Journal of ENGINEERING EDUCATION

March, 1961 *Table of Contents* Vol. 51, No. 7

Teaching Positions Wanted 534

Do You Know 535

Industrial Participation in ASEE, a Special Report 538

Trends in Specialization in Engineering E. D. West 545

Training Engineering Scientists—the Need for New Techniques Hugh Taylor 552

University of Kentucky—a Youngster Nearing 100 557

On University Courses in Materials for the Engineer W. R. Micks 561

Teaching Design for the Rest of the Twentieth Century P. F. Chenea 566

Professional Graduate Study in Engineering M. P. O'Brien 571

Engineering Graphics—a Predictor for Academic Performance in Engineering S. M. Slaby and A. L. Bigelow 581

The Production and Use of Motion Pictures for Engineering Instruction E. J. Rising 588

Biomechanics Research H. R. Lissner 594

Professional Grade Surveying for Civil Engineers M. O. Laird 599

Growth in Undergraduate Hydraulic Engineering J. C. Guillou 606

Notes

Nuclear at Columbia 551

Co-op Doctorates 556

MSU to Advise in India 570

New Materials Degree 580

Rutgers Adds 598

New Dean at Dartmouth 605

Books Beat TV 612

Copyright © 1961, The American Society for Engineering Education

Editorial Committee for the Journal of Engineering Education

Paul T. Bryant	Editor of the Journal and Chairman
Stanley Backer	Massachusetts Institute of Technology
C. E. Bennett	University of Maine
G. Walter Bergren	Purdue University
T. A. Boyle	Duke University
A. H. Cooper	University of Connecticut
R. O. Darling	General Motors Corporation
A. W. Davis	Iowa State University
J. T. Elrod	University of Houston
Amy V. Hall	University of Washington (Prof. Emeritus)
E. W. Jacunski	University of Florida
J. J. Kauzlarich	Worcester Polytechnic Institute
Arthur Lesser, Jr.	Stevens Institute of Technology
G. A. Marston	University of Massachusetts
T. L. Martin, Jr.	University of Arizona
Jeanne I. Miller	McGraw-Hill Book Company
W. E. Miller	University of Illinois
J. H. Moriarty	Purdue University
S. P. Olmsted	Rensselaer Polytechnic Institute
W. E. Restemeyer	University of Cincinnati
J. A. Roberson	Washington State University
R. A. Sencer	Rensselaer Polytechnic Institute
G. Reed Shaw	Rensselaer Polytechnic Institute
G. D. Sheckels	University of Massachusetts
W. F. Stokey	Carnegie Institute of Technology
R. E. Swift	University of Kentucky
B. H. Ulrich, Jr.	West Virginia University
H. L. Wakeland	University of Illinois

Teaching Positions Wanted

INSTRUCTOR–ELECTRICAL ENGINEERING or Physics. Three years teaching experience. Age 34. Resume upon request. Write 51-6 *Journal of Engineering Education*, University of Illinois, Urbana, Illinois.

PROFESSIONAL ENGINEER – PH.D. in highways and soils–Mature–15 years academic–5 years private practice–Desire return to university as dean of engineering, head of CE department, or director research program. Write 51-4 *Journal of Engineering Education*, University of Illinois, Urbana, Illinois.

Do You Know

► That sometimes it is desirable to know what conclusions others reach after taking a critical look at what you are doing? That is what this "Do You Know" is, the "implications" from the report, *Liberal Education and Engineering*, by E. J. Holstein and E. J. McGrath. Under a grant from the Carnegie Corporation of New York, the Institute of Higher Education at Teachers College, Columbia University, has made studies of a number of undergraduate professional curricula and published reports dealing with various aspects of liberal education, particularly as it constitutes a part of preparatory education for the practice of various professions. Copies of the 132-page report can be obtained from the Bureau of Publications, Teachers College, Columbia University, for $2.75 per copy. The following section from the report is reprinted here with the permission of the Bureau of Publications, Teachers College, Columbia University.

Implications

"If one were assigned the task of understanding the true nature of some lost civilization and were given the choice of data on only one institution in that society, he would be wise to ask for a description of the curricula in its schools. For a society's educational system is a more accurate mirror of its hopes and accomplishments—its foibles and failures—than any other single institution. But in a living society we are, in fact, always educating for the future. Therefore, education must do more than simply reflect the present face of a society; it must also hypothesize a probable future image and use this image as a basis for the formulation of its aims. It is in this sense that education "reconstructs" society.

"From one vantage point, the evidence produced and the opinions amassed in this inquiry constitute an indictment of engineering education for its preoccupation with the "mirror" function of education, for its obsession with training for present (and even past) duties, rather than educating for, and creating, probable future responsibilities. It has been shown, however, that some engineering educators who saw engineering education succumbing to narrow utilitarianism—to an unscientific, "engineering-is-an-art" philosophy, have always resisted these tendencies, and they have been restive under this philosophy.

"The present evidence discloses a spreading of this discontent to all sectors of engineering education. Hence, it is neither visionary nor tendentious to postulate the beginnings of a revolution in the philosophy of engineering education and a "stem-to-stern" overhauling of the engineering curriculum. As a prelude to this reconstruction what summary view of engineering attitudes toward socio-humanistic studies can be offered and what recommendations can be made as a guide for future progress?

"One thing is evident. Engineering is now a dynamic complex. Some traditional ideas naturally do and should persist with regard to the proper purposes and character of engineering education. Among many members of the profession, however, there is the clear recognition of new forces at work and new factors consequently to be taken into consideration.

"The first of these is doubtless an awareness that engineers must be educated for more varied activities and broader responsibilities. One need only examine the roster of engineers in high places in Washington to recognize this fact. The second is the consciousness that engineers—like all other citizens who enjoy the advantages of a higher education—have a social responsibility to be informed and intelligent about an increasing range of matters of public policy whether they reach positions of prominence or not. This is the rising but still small price we all pay for the privilege of living in a free society in a dan-

gerously antagonistic world. The third consideration is the enormous acceleration in the growth of knowledge in the basic and in the engineering sciences coupled with the multiplication of specialized occupations within the field of engineering itself.

"Considered together these things appear to lead to certain conclusions. The first of these is that if the four-year undergraduate program is to be retained, as still seems to be the wish of the majority, and if the general education of engineers is to be expanded, some adjustment must be made in the conventional offerings. Such a process of adaptation to the realities of contemporary professional and civic life was begun in certain engineering schools before World War II. The process has since been accelerated and also extended elsewhere.

"In these institutions the room needed to accommodate a broader and more richly varied program in the humanities and the social sciences has been provided by moving out an equivalent amount of instruction in engineering. But this reduction has not handicapped the graduates of these institutions because it has been accomplished by ridding the curriculum of shop work, miscellaneous detailed knowledge, and specialized learning which belongs in the postbaccalaureate years. It has been accomplished, too, by the establishment of a basic or core curriculum for all engineering students which provides the foundation of fact, generalization, principle and theory on which the future education of all professionally growing engineers must rest. Thus the fledgling engineer begins his work grounded in the general theory of his subject, and capable of increasing his knowledge and skills by experience and additional education, and generally educated for the common responsibilities of life which are today the inescapable lot of those to whom society has given the privilege of a tutored mind.

"It is this goal toward which the majority of engineering educators seem to be striving, some with their ideas clearly formulated, others still in the process of reconciling the need for professional competence of a high order and the more inclusive demands of modern life. That some schools of engineering have be able to their own limited satisfaction a least to achieve this goal suggests th others can and should do so.

"This latter point, which was the bu den of the report, "General Education i Engineering," cannot be overstressed Many prominent engineering schoo have already met, or nearly met, the 2 per cent recommendation of the ASE of their own accord without accredita tion pressures, and a few already exceed these requirements.

"Furthemore, it is doubtful whethe the 20 per cent rule will remain th dominant theme in the orchestration o the complex composition of engineering education. The views, the opinions, and the aspirations expressed by so many fac ulty members and administrative officers suggest rather that the ideal proportion of liberal studies in the next decade wil more closely approximate 30 per cent o the engineering curriculum.

"Certainly, if the thinking at the Massachusetts Institute of Technology, long a leader in engineering education, pre ages the accomplishments of the next decade, such optimism about the increas ing importance of the humanities and so cial sciences on engineering campuses is completely justified. Ten years ago the "environment at M.I.T. was enlarged in scope by the founding of the School of Humanities and Social Sciences" to be followed closely by the emergence of "the concept of M.I.T. as a university of special objectives." Further develop ments were reviewed and predicted by a faculty committee at M.I.T. in 1959:

> In 1951 the university concept moved forward with the establishment of the Center for International Studies where scholars in economics, humanities, international relations, and communications have federated to benefit from one another's expanding knowledge and to cope with larger problems of human need. This was the forerunner of a series of similar undertakings which we believe are destined to play a most important role in the future.

"It is difficult, indeed, to envision the humanities and social sciences languish-

ing in the future intellectual climate suggested by these accomplishments and high hopes.

"While attempting to reach the more ideal goal of 30 per cent of social sciences and humanities the immediate task of those who seek to liberalize the education of the engineer is twofold. First, they must provide for all their students at least one course per semester which is genuinely humane or social. Second, they must insure that these courses, in introducing the student to the humanities and social sciences, are all part of a planned program in which one course builds upon, or is related to, another. Such a program must provide some exploration in depth and capitalize on the increasing maturity of students in the junior and senior years. The content of such programs should be selected and coordinated (or integrated) in accordance with the principles resulting from an ovedue redefinition of aims, coupled with all-out, serious attempts to evaluate the educational results. The results of such evaluations must be given the widest publicity so that every school which is now intuitively convinced that it is turning out the best product possible with the resources at its disposal can be guided in its planning by the more reliable and objective results of systematic, controlled studies.

"The long-range task of engineering educators is even more challenging than the immediate, for, in the long run, they must somehow find more room for liberal studies than one-fifth of a four-year curriculum. They must frankly recognize that the value of specialization which grows out of a narrowly prescribed technical education, narrowly taught, falls far below that which results from a broad educational experience. Exercising his traditional independence, the engineering educator must not be content to coast along, but, rather, must be constantly alert to the possibility of making the curriculum more fundamental and general, of condensing and liberalizing the teaching of professional subjects, of discouraging excessive specialization below the graduate level, and of increasing the socio-humanistic content as much as, and wherever, possible. Only by such constant striving to include more courses dealing with man and his institutions can he validate his oft-repeated claim that technical education is the truly liberal education for the modern world. Only by being constantly alert to the need to provide a balanced education involving both professional and general studies can the engineering profession attain the new status for which it strives and which it deserves in this dynamic world.

"The education of future leaders simultaneously skilled in science and technology and sensitively aware of the problems mankind now faces, is no longer an expendable luxury; it is an indispensable prerequisite for the continuing technological, social, political, and economic success of America, and indeed for its survival. Here is an unparalleled opportunity for these schools to pioneer in the development of a balanced and fundamental higher education sufficient for living and working in a world both reassured and unnerved by breath-taking technological progress."

These have been the "implications" seen by authors Holstein and McGrath. If you would like to see the materials from which these implications were drawn, they are in *Liberal Education and Engineering*.

W. Leighton Collins
Secretary

Industrial Participation in ASEE

A SPECIAL REPORT

Reason for Study

It is a well-established fact that at least six out of ten, if not more, of the graduates of engineering curricula will find the outlets for their training in the industrial complex of our economy. With the exploding technology of the last fifteen years, educators are giving considerable attention to the current and anticipated procedures for training engineers to meet the demands of our economy in the future. Questions as to the extent to which engineers should receive other than technical training in their academic work, the amount of new technology in specialized fields that should be given, the relationship of industrial education to the academic foundation the engineer of tomorrow will have, and the extent to which the users of engineering services desire a more extensively-trained product from our engineering schools are some of the complex problems being discussed.

It is obvious with so much of our engineering talent being utilized by industry that as extensive liaison as possible should be established between engineering educators and the industrial employers of engineering graduates. The American Society for Engineering Education should be an obvious vehicle for establishing this liaison. A review of the membership of the American Society for Engineering Education, however, indicates a disturbing absence of membership from engineers in industry and of participation of industrial representation in various facets of the Society's activities. The Council of the American Society for Engineering Education, taking note of the above facts, requested the Relations with Industry Division to inquire into this problem with the ultimate objective of recommending to the Society ways by which more extensive liaison could be established between the educators participating in the American Society for Engineering Education and the industrial users of engineering graduates. The Relations with Industry Division established a task force, which has begun work on this question, and presents herewith the first interim report of this study.

The Task Force has met with a number of officers of the Society and has coordinated its considerations with the Planning Committee of the Council. It was decided that the first step needed was to determine the attitude of officials of ASEE, not only of the extent to which industrial participation should be encouraged, but seeking their recommendations as to how it might be enhanced. The Task Force, therefore, developed a questionnaire which was sent to several groups of leaders of the Society.

Procedure of Study

Three groups of Society officials were immediately identifiable through headquarters' records; and the questionnaire, Appendix A, was addressed to these individuals. The groups were (1) the current and immediate Past Council members; (2) the current chairmen of committees and divisions; and (3) the chairmen of local sections. Forty questionnaires were returned from the first group; 27 from the second group, and 10 from the third group, making a total of 77 questionnaires. There was no appreciable difference in the replies from these groups; and while some of the questions have lent themselves to breakdowns according to the groupings, the general commentary can best be accomplished as a composite of the 77 questionnaires returned.

Analysis of Replies

Table 1 indicates the response to the first question as to whether or not there is sufficient industrial participation in ASEE affairs. It will be noted that almost six out

TABLE 1

IN YOUR OPINION, IS THERE SUFFICIENT INDUSTRIAL PARTICIPATION IN ASEE AFFAIRS OR WOULD YOU LIKE TO SEE MORE?

	Council	Committee & Division Chm.	Section Chairmen
O.K. as is	8	6	1
Need More	31	21	9
No Answer	1		

of seven of those replying indicated they felt there was need for more industrial participation.

Question 2 endeavored to probe the areas in which the individuals felt such participation might be most helpful. The significant response here was the predominant indication at all levels of Society leadership that participation in regional section meetings would be most desirable. Institutional membership, RWI activities, and the Annual Meetings also received high indication of desirable activity. There appeared to be little feeling that industrial participation in ECAC or ECRC would be particularly fruitful. Some rather specific activities were also noted.

Probing further for specific suggestions of the nature of contributions to be made by industrial representatives led to a number of suggestions. The most frequently suggested contribution was in the form of participation in meetings and programs, and to provide information about the needs of industry. Table 3 lists the more frequently suggested specific contribution.

There was almost unanimous opinion on the part of the respondents that ASEE could develop programs which would be of greater interest to industry. A number of suggestions were made as to what ASEE could do in this direction, the more frequently-listed suggestions being tabulated in Table 4.

An analysis of representatives of industries holding institutional membership in ASEE indicates they are frequently those concerned either with the recruiting activities

TABLE 2

IF MORE PARTICIPATION IS NEEDED, IN WHAT AREA OR AREAS MIGHT IT BE MOST HELPFUL? (CHECK AS MANY AS YOU WANT)

	Council	Committee & Division Chm.	Section Chairmen
Institutional Membership	21	11	8
RWI Activities	16	11	9
ECAC	4	1	—
ECRC	6	2	2
Annual Meetings	18	14	4
Regional Section Meetings	28	17	6
Other:			
Cooperate financing regional Section activities			
Participation in divisions of Society and division meetings			
Engineers in industry closer to engineering education			
Financial aid			
Curriculum discussions at Annual Meetings			
Concern with dearth of Ph.D.'s			

TABLE 3

WHAT SHOULD BE THE NATURE OF CONTRIBUTIONS MADE BY INDUSTRIAL REPRESENTATIVES?

Serve as officers
Participate in meetings and programs
Money and equipment to schools
Provide information about needs, etc., of industry
Present technical papers
Persuade young men to go into teaching
Partake in discussion of engineering education problems
Discuss utilization of engineers
Suggest career guidance activities for students
More active participation in planning curricula
Inform other industries about ASEE
Real and realistic appraisal of requirements and demands made upon engineering graduates—advice from industry as to how well we are serving their needs

or educational programs of the company. It has been suggested that perhaps it would be helpful if there were more membership and activity in ASEE on the part of engineers in industry actually doing engineering work. This question was posed in the questionnaire. The response was overwhelmingly in the affirmative. A few of the respondents felt such participation should be limited to engineers with some activity associated with education, perhaps even to the extent of teaching part time. See Table 5.

Since a great deal of the orientation for industrial participation in ASEE is through the Relations with Industry Division, it was felt desirable to attempt to evaluate how extensive the activities of RWI are known among the leaders of the Society and to seek their suggestions as to improvement in the RWI program. Question 6 en-

TABLE 4

DO YOU THINK ASEE COULD DEVELOP PROGRAMS WHICH WOULD BE OF GREATER INTEREST TO INDUSTRY? PLEASE SPECIFY HOW.

Expand and vitalize RWI programs, particularly at Section level, permitting greater frequency at meetings—also regional and Annual Meetings.

Devote more sessions specifically to problems of mutual interest to industry and education.

Cooperative ventures with industry permitting young engineers to be on furlough to take graduate work—industrial job study—problem of motivation of students to raise level of scholarship.

Let industrial members know participation is desired and advise more fully of aims and objectives.

Get industrialists on program and heed their advice.

Increase current efforts to provide closer liaison among professional societies and ASEE.

Working together of education and industry to further engineering education and obtain mutual raising of educational and professional standards.

TABLE 5

WOULD IT BE HELPFUL, IN YOUR OPINION, IF MORE ENGINEERS IN INDUSTRY DOING ENGINEERING WORK WERE ACTIVE IN ASEE?

	Council	Committee & Division Chm.	Section Chairmen
Yes	36	25	8
No	1	1	—
Not Sure	3	1	2

deavored to secure an indication of the degree of familiarity with the activities of RWI. Table 6 indicates that only about 1 in 6 of the respondents is well informed of RWI activities, and unfortunately, a third of the respondents indicated a surprising lack of information concerning RWI.

Unfortunately, it appears that the Annual College-Industry Conference sponsored by RWI and held in various parts of the country has not attracted the participation

TABLE 6

HOW FAMILIAR ARE YOU WITH ACTIVITIES OF RWI?

	Council	Committee & Division Chm.	Section Chairmen
Well informed	7	6	1
Fairly well informed	21	13	7
Know that such division exists, but don't know much about it	10	6	2
Would like more information about it	3	7	1

TABLE 7

HOW MANY OF THE ANNUAL (IN JANUARY) COLLEGE-INDUSTRY CONFERENCES HAVE YOU ATTENDED?

	Council	Committee & Division Chm.	Section Chairmen
None	24	17	8
One	8	5	1
More than One	8	5	1

TABLE 8

DO YOU ATTEND ANY OF THE RWI SESSIONS AT THE ANNUAL MEETING?

	Council	Committee & Division Chm.	Section Chairmen
Yes	27	20	5
No	13	7	5

TABLE 9

HAVE YOU EVER APPROACHED AN INDUSTRIAL ORGANIZATION REGARDING MEMBERSHIP IN ASEE?

	Council	Committee & Division Chm.	Section Chairmen
Yes	10	10	3
No	29	17	7

of the leadership of ASEE. Only a third of the respondents had attended any of these College-Industry Conferences. See Table 7.

Much better participation by the leadership of ASEE in the RWI sessions at the Annual Meeting, however, was noted by the respondents. Even here, however, a third of the respondents had not participated in these sessions. A possible reason,

of course, exists here in that these leaders may have other responsibilities at the time RWI sessions are held at the Annual Meeting. See Table 8.

Despite the interest of the respondents in having greater industrial participation in ASEE, there has been little attempt on their part to secure industrial membership. Less than one-third of the respondents had ever approached an industrial organization regarding membership. A further question was asked of those who indicated they had had experience in seeking industrial members, and the most common comments noted by them are included in Table 9.

What Did They Say

We do not have staff qualified to benefit from meetings regarding engineering education.

Felt ASEE essentially an organization for college teachers

Unfamiliar with need for membership

Saw little advantage; thought academic discussions had little merit for industrial organization.

The opinion of the ASEE leadership was sought as to what might be the reason for the comparatively few industrial memberships maintained in the Society. The most common comment received in response to this question was a lack of information and understanding of the objective of ASEE, a lack of awareness of the advantages of belonging, and the lack of an aggressive solicitation program on the part of the Society. Several other worthwhile opinions were made and are noted in Table 10.

TABLE 10

AT PRESENT, RELATIVELY FEW COMPANIES MAINTAIN INDUSTRIAL MEMBERSHIP IN ASEE. WHAT WOULD YOU SAY IS REASON?

Lack of information and understanding of objectives
Lack of aggressive solicitation
Lack of profitable contacts
Not aware of advantages of belonging'
They are not served—have no obvious return
Have no opportunity to contribute
Believe education belongs to professors
Programs not challenging enough
Not worth what it costs
ASEE lacks people with time to sell ASEE to industry
Insufficient responsibility and recognition for present members
Industry not concerned enough about teaching to be interested
Industry satisfied with jobs schools presently doing

Summary

There is overwhelming opinion among the leadership of ASEE that more participation on the part of engineers in industry is desirable.

This participation should be encouraged through institutional membership and participation in regional section meetings, RWI activities and the Annual Meeting.

ASEE should expend more effort in developing programs of greater interest to industry.

More engineers in industry doing actual engineering work should be encouraged to participate in the considerations of ASEE.

The activities of RWI are not well known to the leadership of ASEE.

There is a disturbing lack of participation on the part of the ASEE leadership in the College-Industry Conferences.

Leadership of ASEE is doing little to seek industrial membership in ASEE.

ASEE leadership feels a deficiency on the part of the Society in encouraging industrial membership.

Recommendations

The Task Force would make the following recommendations to RWI:

(1) That this report be forwarded to all members of Council;
(2) That the Task Force be continued for another year to consider specific recommendations for activity and programming on the part of RWI;
(3) That the Task Force be authorized to meet with officials and other interested units of ASEE to explore further activities of the Society which might be profitable to enlist industrial participation;
(4) That this report be called to the specific attention of the Publicity Committee of RWI for consideration of ways and means by which the RWI activities could be better understood by at least the leadership of ASEE;
(5) That an appropriate group of RWI meet with the ASEE Committee on Industrial Memberships to coordinate an aggressive program with industry to acquaint them with ASEE activities and encourage their participation in the Society, and particularly in RWI.
(6) That RWI extend added effort in securing participation of the leadership of ASEE in the annual College-Industry Conference.

June 1960

RWI Survey Task Force

H. Russell Bintzer
George D. Lobingier
J. F. Downie Smith
Cornelius Wandmacher
Paul H. Robbins, *Chairman*

Questionnaire on Industrial Participation in American Society for Engineering Education

The Relations with Industry Division (RWI) of the American Society for Engineering Education (ASEE) is endeavoring to determine the desires of members of Council and other ASEE leaders as to the extent of their desire for participation of industry in the activities and programs of the ASEE.

We are soliciting your cooperation in commenting on the following questions. We would appreciate your frank comments on these items. Thank you!

1. In your opinion, is there sufficient industrial participation in ASEE affairs or would you like to see more? O.K. as is ..... Need more .....

2. If more participation is needed, in what area or areas might it be most helpful? (Check as many as you want)

( ) Institutional membership
( ) RWI activities
( ) ECAC
( ) ECRC
( ) Annual Meeting
( ) Regional Section Meetings
( ) Other _____
(Please specify)

3. What should be the nature of contributions made by industrial representatives?

4. Do you think ASEE could develop programs which would be of greater interest to industry? Please specify how.

5. Would it be helpful, in your opinion, if more engineers in industry doing engineering work were active in ASEE?

APPENDIX A

6. How familiar are you with activities of RWI?
   ( ) Well informed
   ( ) Fairly well informed
   ( ) Know only that such division exists, but don't know much about it
   ( ) I would like more information about it
7. How many of the annual (in January) College-Industry Conferences have you attended?
   .....None .....One .....More than one
8. Do you attend any of the RWI sessions at the Annual Meeting?
   Yes..... No.....
9. Have you ever approached an industrial organization regarding membership in ASEE?
   If so, what did they say?
10. At present, relatively few companies maintain industrial membership in ASEE. What would you say is the reason for this?

Name.....

January 1960 ASEE Position.....

Please return to: Paul H. Robbins, 2029 K Street, N. W., Washington 6, D. C. (envelope attached)

APPENDIX A-2

Trends in Specialization in Engineering

ELMER D. WEST

Director, Office of Statistical Information and Research, American Council on Education

One of the most publicized sets of data in higher education relates to the field of engineering. The continued decline in engineering enrollment in both total opening and first-time (freshman) opening, at a time when the combined enrollment in all fields has been increasing, has been the source of much public concern.

Much less frequently is attention given to the areas of specialization within the engineering field. "Shortages" are relative. An overproduction of "engineers" could still lead to a shortage in some categories of engineering; and an "underproduction" of total engineers might still result in a surplus in a given sub-specialty. However, without reference to "need," or to "shortages," an analysis may be made of what is happening in the various specialties of engineering in which degrees are granted.[1]

[1] Figures used were those reported in *Journal of Engineering Education* for the years presented.

Prepared with the assistance of Miss Marjorie Mowl, Research Associate.

Figure 1 shows the total number of engineering degrees granted, 1949–50 annually through 1958–59, bachelors' or first professional level, in seven subcategories: aeronautical, chemical, civil, electrical, industrial, mechanical, metallurgical, plus an additional "all other." A casual glance reveals high initial production, a marked decline, and then indications of recovery. This is particularly pronounced in both mechanical and electrical engineering. It is also noted that the largest number of degrees awarded were in mechanical engineering until 1956–57, when electrical engineering moved into first place.

Figure 2 expresses these figures as percentages of the total engineering degrees awarded in each year. To illustrate: in 1949–50 the 1,279 degrees granted in aeronautical engineering constituted 2.7% of the total engineering degrees awarded that year. The highest percentage of degrees awarded was in mechanical engineering for the first seven years, when electrical engineering moved into first place. The low percentage point for these two fields was 1952–53; but mechanical engineering has increased

TABLE 1

NUMBER OF ENGINEERING DEGREES, BY FIELD, AT THE BACHELOR'S LEVEL

Year	Aero.	Chem.	Civil	Elec.	Indus.	Mech.	Met.	All Other
1949–50	1,279	4,422	7,312	12,340	2,868	13,056	950	5,933
1950–51	1,094	3,614	6,473	8,616	2,256	9,609	797	5,445
1951–52	694	2,743	4,917	5,876	1,573	6,823	578	3,951
1952–53	595	2,183	4,070	4,415	1,243	5,284	542	3,310
1953–54	606	1,988	3,597	4,076	1,103	4,827	486	3,024
1954–55	628	1,952	3,557	4,500	1,174	5,248	436	2,705
1955–56	821	2,376	3,888	5,777	1,391	5,985	477	2,832
1956–57	984	2,712	4,275	7,510	1,595	6,952	572	3,148
1957–58	1,188	2,920	4,673	8,712	1,783	7,859	662	3,419
1958–59	1,363	3,013	4,939	9,837	1,904	8,300	710	3,629

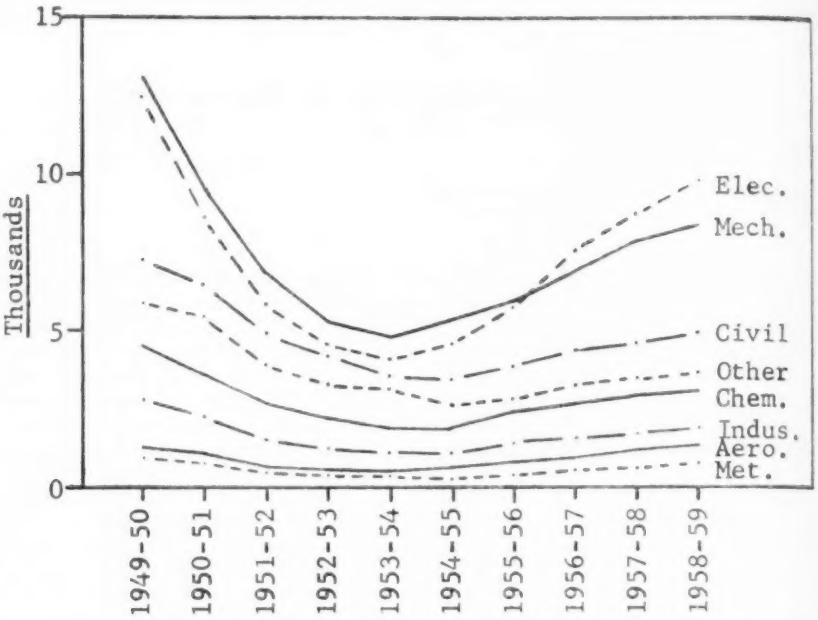


FIG. 1. Number of engineering degrees, by field, at the bachelor's level.

from a low of 24.4% that year to only 24.6% in 1958–59, while electrical engineering has moved from 20.4% to 29.2%. Although small percentage fluctuations occur in successive years, the percentages of degrees in 1949–50 and 1958–59 were essentially the same in chemical, civil, industrial and metallurgical engineering. The percentage increase for aeronautical engineering was small, but relative to its 1949–50 percentage it is substantial.

Data on the masters' (second level) degrees show numbers markedly lower than on the bachelor's level, but for the years indicated, there has been an increase at the master's level in the number of degrees granted in six of the fields that showed a decrease at the bachelor's level. This is true in civil, electrical, industrial, mechanical, metallurgical, and "all other." In electrical, the increase is over 50% and, in industrial, over 100% above the 1949–50 figures. Only chem-

TABLE 2

PER CENT DISTRIBUTION OF ENGINEERING DEGREES, BY FIELD, AT THE BACHELOR'S LEVEL

Year	Aero.	Chem.	Civil	Elec.	Indus.	Mech.	Met.	All Other
1949–50	2.7	9.2	15.2	25.6	6.0	27.1	2.0	12.3
1950–51	2.9	9.5	17.1	22.7	6.0	25.4	2.1	14.4
1951–52	2.6	10.1	18.1	21.6	5.8	25.1	2.1	14.5
1952–53	2.7	10.1	18.8	20.4	5.7	24.4	2.5	15.3
1953–54	3.1	10.1	18.3	20.7	5.6	24.5	2.5	15.3
1954–55	3.1	9.7	17.6	22.3	5.8	26.0	2.2	13.4
1955–56	3.5	10.1	16.5	24.5	5.9	25.4	2.0	12.0
1956–57	3.5	9.8	15.4	27.1	5.7	25.1	2.1	11.3
1957–58	3.8	9.4	15.0	27.9	5.7	25.2	2.1	11.0
1958–59	4.0	8.9	14.7	29.2	5.7	24.6	2.1	10.8

TABLE 3

NUMBER OF ENGINEERING DEGREES, BY FIELD, AT THE MASTER'S LEVEL

Year	Aero.	Chem.	Civil	Elec.	Indus.	Mech.	Met.	All Other
1949–50	326	711	725	1,165	255	824	184	675
1950–51	313	743	661	1,188	269	940	238	782
1951–52	239	540	586	1,016	271	645	136	699
1952–53	211	433	573	876	222	622	126	663
1953–54	219	448	563	978	367	710	139	706
1954–55	202	469	689	1,068	362	750	146	758
1955–56	216	544	820	1,156	341	759	139	703
1956–57	257	602	850	1,307	395	809	140	843
1957–58	301	561	808	1,561	486	947	183	904
1958–59	331	596	926	1,837	577	1,078	205	1,173

ical engineering shows a decline in number.

Figure 4 shows percentages for the second level. The trends show that an increasing proportion of the total degrees at this level occurred in the fields of electrical, industrial, and "all other"; and decreases occurred in aeronautical, chemical, and metallurgical. Civil and mechanical also show a decrease when the 1958–59 figures are compared to those for 1949–50, but the trend over the years shows fluctuations with substantial increases for some years. In general, however, the percentage decreases are relatively slight, except in chemical engineering, which drops from a high in 1949–50 of 14.6% to a low in 1958–59 of 8.9% of the masters' degrees in engineering.

Figures 5 and 6 give data on doctorates in engineering. All numbers are

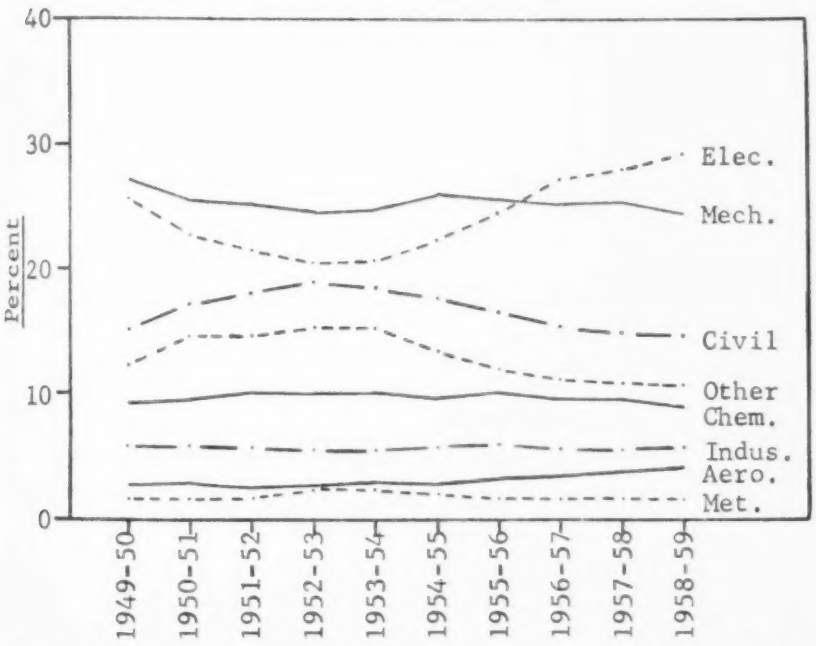


FIG. 2. Per cent distribution of engineering degrees, by field, at the bachelor's level.

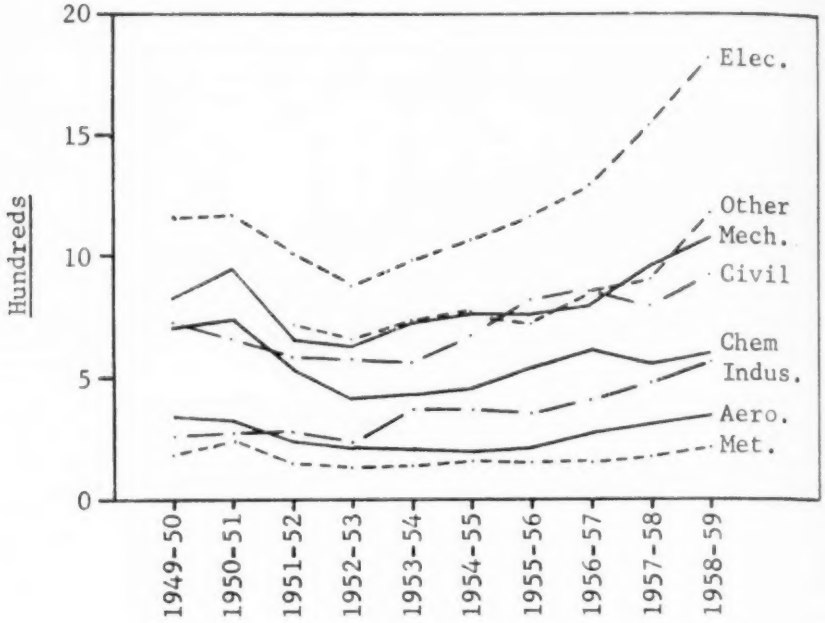


FIG. 3. Number of engineering degrees, by field, at the master's level.

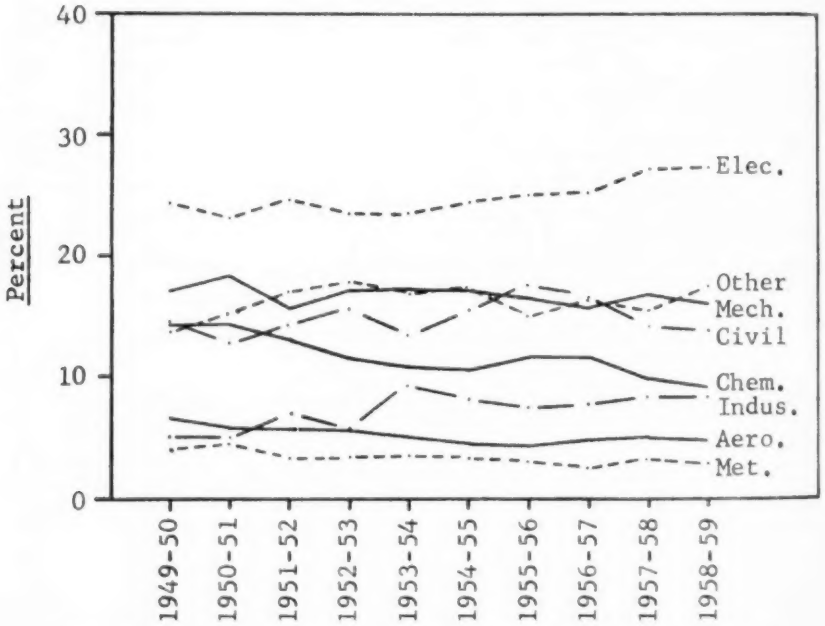


FIG. 4. Per cent distribution of engineering degrees, by field, at the master's level.

TABLE 4

PER CENT DISTRIBUTION OF ENGINEERING DEGREES, BY FIELD, AT THE MASTER'S LEVEL

Year	Aero.	Chem.	Civil	Elec.	Indus.	Mech.	Met.	All Other
1949–50	6.7	14.6	14.9	23.9	5.2	16.9	3.8	13.9
1950–51	6.1	14.5	12.9	23.1	5.2	18.3	4.6	15.2
1951–52	5.8	13.1	14.2	24.6	6.6	15.6	3.3	16.9
1952–53	5.7	11.6	15.4	23.5	6.0	16.7	3.4	17.8
1953–54	5.3	10.8	13.6	23.7	8.9	17.2	3.4	17.1
1954–55	4.5	10.6	15.5	24.0	8.1	16.9	3.3	17.1
1955–56	4.6	11.6	17.5	24.7	7.3	16.2	3.0	15.0
1956–57	4.9	11.6	16.3	25.1	7.6	15.5	2.7	16.2
1957–58	5.2	9.8	14.0	27.1	8.5	16.5	3.2	15.7
1958–59	4.9	8.9	13.8	27.3	8.6	16.0	3.0	17.4

TABLE 5

NUMBER OF ENGINEERING DEGREES, BY FIELD, AT THE DOCTORATE LEVEL

Year	Aero.	Chem.	Civil	Elec.	Indus.	Mech.	Met.	All Other
1949–50	25	178	32	85	3	48	46	75
1950–51	31	174	51	110	5	70	40	105
1951–52	24	159	43	121	6	68	53	112
1952–53	29	147	32	132	3	78	56	115
1953–54	43	133	43	111	6	72	53	129
1954–55	23	139	29	141	9	79	62	117
1955–56	36	136	59	136	10	61	72	100
1956–57	32	146	39	130	17	67	53	112
1957–58	26	127	69	144	9	76	63	133
1958–59	24	143	70	189	12	83	63	130

TABLE 6

PER CENT DISTRIBUTION OF ENGINEERING DEGREES, BY FIELD, AT THE DOCTORATE LEVEL

Year	Aero.	Chem.	Civil	Elec.	Indus.	Mech.	Met.	All Other
1949–50	5.1	36.2	6.5	17.3	0.6	9.8	9.3	15.2
1950–51	5.3	29.7	8.7	18.8	0.9	11.9	6.8	17.9
1951–52	4.1	27.1	7.3	20.6	1.0	11.6	9.0	19.1
1952–53	4.9	24.8	5.4	22.3	0.5	13.2	9.5	19.4
1953–54	7.3	22.5	7.3	18.8	1.0	12.2	9.0	21.9
1954–55	3.8	23.2	4.8	23.5	1.5	13.2	10.4	19.5
1955–56	5.9	22.3	9.7	22.3	1.6	10.0	11.8	16.4
1956–57	5.4	24.5	6.5	21.8	2.9	11.2	8.9	18.8
1957–58	4.0	19.6	10.7	22.3	1.4	11.7	9.7	20.6
1958–59	3.4	20.0	9.8	26.5	1.7	11.6	8.8	18.2

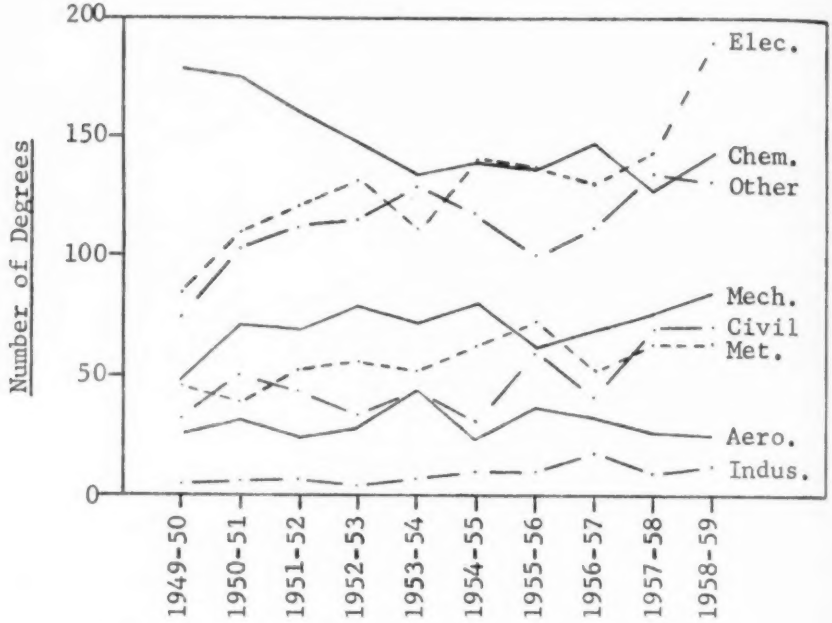


FIG. 5. Number of engineering degrees, by field, at the doctorate level.

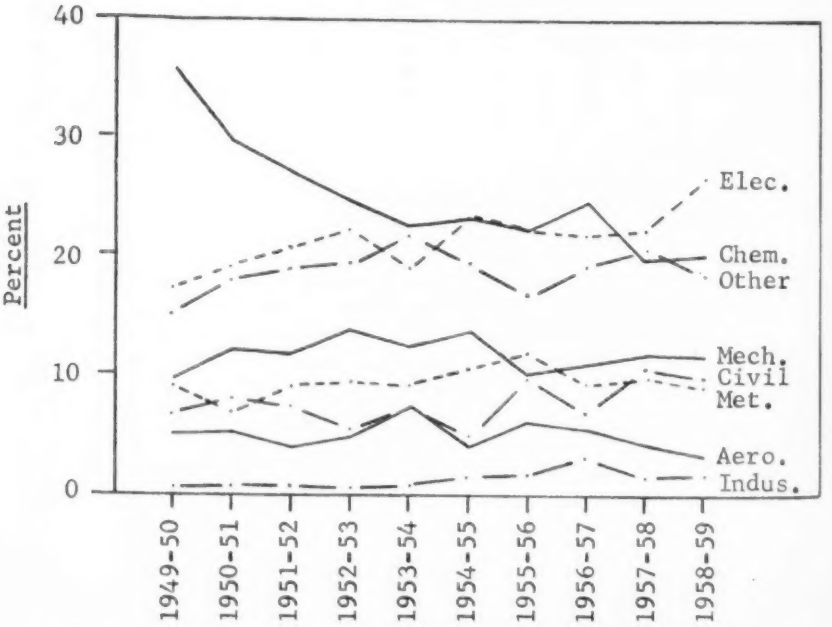


FIG. 6. Per cent distribution of engineering degrees, by field, at the doctorate level.

small, of course, when compared with lower degree levels. However, despite this small size, and despite irregularities, there are rather impressive changes. Chemical engineering drops from 36% of doctorates in engineering in 1949–50 to only 20% in 1958–59. The biggest drop was in 1950–51, but, in general, the decrease has been rather consistent. (Although it is not shown here, the number of doctorates in chemistry, as against chemical engineering, has remained relatively steady since 1950–51 except for the year 1957–58, when they decreased.) The number of doctorates in aeronautical engineering in 1958–59 was about the same as in 1949–50, but the percentage this area is of the total doctorates in engineering dropped from 5.1% to 3.4%. In only one other area, metallurgical engineering, was the percentage lower in 1958–59 than in 1949–50. Civil, industrial, mechanical, "all other," and electrical went up, the last named from 17.3% to 26.5% of the total.

In summary, an unsteady but generally increasing percentage of the total engineering degrees granted in recent years has been in electrical engineering; and this is true at all levels, the bachelor's, master's, and doctorate levels, but especially so at the doctorate level. Over the 10-year period, in chemical engineering, there has been only a slight decrease in the percentage at the bachelor's level; but the decrease at both higher levels is quite marked. For other areas consistent changes in the percentage patterns are less noticeable. It is possible that some of these percentage changes reflect changes in the content of the curriculum as well as in the attitudes of the students selecting the programs.

NUCLEAR PROGRAM AT COLUMBIA

Columbia University's Nuclear Engineering Science Program has been aided by a grant of $247,000 from the National Science Foundation.

Of this amount, $200,000 was awarded to purchase an experimental, water-moderated nuclear reactor. The remaining $47,000 will be used to outfit "hot cells," rooms where radioactive materials and waste products are handled in safety.

The reactor will have a continuous rating of 10 kilowatts, but will have the potentiality of "flashing" for a few milliseconds to a relatively high power. This will permit research requiring high power but which needs only a very short exposure.

The reactor will be utilized for research by Columbia's faculty and graduate students under the guidance of the Nuclear Engineering Science Committee, composed of professors in the School of Engineering and other interested departments of the University, particularly Physics and Chemistry.

Dr. Charles F. Bonilla, of the Nuclear Engineering Science Committee and supervisor of the grant, said qualified personnel from other institutions in the New York Metropolitan area also would be able to make use of the new unit to conduct experiments, which could not be done in their own laboratories, whenever the Columbia reactor was not being fully utilized. The new unit is, so far, the only one scheduled to be situated within 50 miles of New York City.

This year, for the first time, the University is offering the degree of Nuclear Engineer. The "N.E." degree is designed for persons who plan to carry their course work one year past the master's degree but do not need to carry out an intensive doctorate research to complete their educational program.

Training Engineering Scientists–

The Need for New Techniques

HUGH TAYLOR

President, Woodrow Wilson National Fellowship Foundation

During this conference we have heard discussions on understanding the learner and then on understanding the learning process. Professor Harlow's studies were mentioned in this connection. In the December 1959 issue of the *American Scientist*, you, and perhaps your graduate student assistants, can learn something from what Professor Harlow has there recorded about the learning process with rhesus monkeys. These have advantages which the human infant does not possess. They are apparently ideal subjects for study since, unlike humans, they obtain locomotion after a few hours of life and their initial process of learning can be followed even during the first days of their existence. Professor Harlow finds that, at 30 months, the monkey has not yet fully acquired all his learning skills. So there is still hope for the adolescent human.

I heard something of the Hawthorne experiment,[1] and the factors of status and guinea pig in the final session. That took me right back to 1912 and the discussion of the effect of high tension currents, a kind of corona discharge in the classroom, on the efficiency of the learning process. A class in Finland was divided into two sections. One worked in a room which was fitted with wires at high tension, the other without. The children in the high tension room always seemed to be more able, their grades were always better until, unknown to the teachers, the professor switched the high tension between the two rooms. The children initially under high tension continued to be superior because the teacher, not knowing of the tension switch, was determined that her children would be the superior group in order that the pro-

Learning to teach and, in the larger sense, becoming an engineering educator, are processes about which we really know very little. They continually take place, they are very important, and they will soon become urgent. After much thoughtful study, the Committee on the Development of Engineering Faculties of ASEE organized the Cleveland Conference of 19–21 November, 1959, to bring together a small group who could identify and assemble the resources in our own and other fields, including formal education, that can best aid this process of learning to become a teacher and educator. This paper is one of the series originating from that Cleveland Conference.

An address to the Conference on the Development of Young Engineering Faculties held at Cleveland, Ohio on November 19–21, 1959 under the auspices of the Committee on the Development of Engineering Faculties of ASEE. The author, now President of the Woodrow Wilson National Fellowship Foundation, was, until his recent retirement, an active member of the Chemistry Department of Princeton University since 1914 and Dean of its Graduate School since 1945. A native of England, he has retained British citizenship and has been active in scientific societies on both sides of the Atlantic. His many honors include British and Papal Knighthoods.

[1] This study, conducted at the Hawthorne works of the Western Electric Company, found that, with understanding and intelligent supervision, production continued to increase despite the experimental introduction of poor illumination in the working environment of a small test group. Fritz J. Roethlisberger and William J. Dickson, *Management and the Worker* (Cambridge: Harvard University Press, 1939).

fessor's preconceived idea should be validated.

My next observation concerns the role of psychology in the evaluation process. It goes back to World War I and the measurement of the GI of that particular war by the psychologists, and the remarks of Professor Wilder D. Bancroft of Cornell anent these activities. He said that they, the psychologists, believed that if you make a large enough number of measurements you will get the right answer even though you have the wrong measuring stick. Or, just a few years later, Professor Bowman, Professor of Philosophy in Princeton University, about to return to his native heath in Glasgow to resume his philosophic activities in that part of Scotland, was induced by Dean West to address the graduate students on the place of philosophy in graduate education in the country. In the course of his remarks he said, "Philosophy out of her capacious bosom has begot many offspring, among others, psychology—an infant, like all infants, red, raw, and vociferous." Psychology has had time, however, since just after World War I, to grow up to its present stature.

Let us now consider three techniques of learning which came up for discussion in this conference. One is the traditional method, recitation and classroom exercises, the practice of quizzes and the like, that seems to aid in the final grade attained. The second is the technique of learning by discussion, what Woodrow Wilson at Princeton in 1905 devised and designated as the preceptorial system. The third method that we heard talked about was the method of learning by independent study.

Here I want to say that, since 1924, and therefore with 35 years of background, all A.B.'s in Princeton have enjoyed these three modes of instruction. As with the rhesus monkeys of Professor Harlow, it appears that, with advancing adolescence, one can pass progressively from (a) the traditional method of quizzes, through (b) learning by discussion, to (c) the role of independent study. In Princeton we find that each has its place in the learning process. The traditional method, recitation, is dominant at the freshman level where you have just made the transition from the high school curriculum. But we feel that (c), the method of independent study, should be dominant at the junior and the senior levels and it is in that respect that, in my judgment, the engineering curriculum of Princeton still does not match the curriculum that obtains in the rest of the university and which, in my judgment also, has yielded enormous values to the students who have been put through the process.

Two of my advisees came around the corner of my office in May of one year, at the time when they should have reported on their independent study for the junior year. I said to them, "You're in a very peculiar position, aren't you?" They said, "Yes, we are; we've come to see what we can do about it." I said, "Well, I'll tell you what you can do about it. I will give you the lowest grade for your independent study that will enable you to stay in college. But, on the Monday morning after Commencement in June, at 8:30 I will expect you to be in my private laboratory next door and for the next six weeks from 8:30 until 5:00 in the evening, from Monday till Friday, you will do the work of independent study that you should have done during the academic year that has just gone by." They said, "All right." At 8:30 on Monday following Commencement, they were in the laboratory. They had a very interesting time. They really enjoyed themselves. One of them investigated the elements of the Fischer-Tropsch processes of gasoline synthesis. When I saw his father in October, following the summer, he said to me, "I don't know what you did to my son, who is just out of his junior year and entering upon his senior year." I said, "What did I do to your son?" "Well," he said, "you made him like a graduate student." That was all, "You made him like a graduate student." Independent work, independent study, a gradual transition from the technique of recitations and quizzes to a larger degree of independence and personal responsibility, starting in the junior year some-

times with success, but other times requiring a discipline or a measure to insure its fulfillment, is the best kind of preparation for the graduate instruction in the years ahead, we have to look to at the present time. I would say the graduate years should be characterized by an increasing emancipation from the classroom. Graduate education must become increasingly self-education.

I would like in that connection to tell you the story of President Eisenhower's scientific advisor. When Dr. Killian returned to Massachusetts Institute of Technology, Harvard took over and the scientific assistant to the President was Professor George B. Kistiakowsky, whom I had the honor to bring to the United States. I thought the really dramatic aspect of the dinner that the President of the United States gave to the Premier of Russia recently was that there was present at the dinner as President Eisenhower's scientific assistant, one George B. Kistiakowsky, who, in 1919, was fighting with Denikin's army in South Russia. I wonder whether the Premier of Russia really took in the full import of that particular transition. Kistiakowsky was incarcerated after the failure of the Denikin expedition, first of all in Istanbul and then in Salonika. Salonika was a very considerable improvement on Istanbul because the people in charge of the camp were French, and they were careless, and it was quite easy for the Russians to disappear from the camp.

So Kistiakowsky spent the next year working his way up through the Balkans, earning his living by replacing the broken glass in the houses, of which there was a good deal in Yugoslavia at that time. He finally worked his way up to Berlin. In Berlin he entered the laboratory of Bodenstein to take a degree in physical chemistry. He didn't have very much money and it was necessary for him to get through his doctor's degree in the quickest time possible. At that time, it was necessary for a Ph.D. in Berlin to register for the courses of certain professors and to pay fees for those courses to the professors whether they attended the lectures or not. Kistiakowsky, having paid his fees, had to decide whether it was more worth his while to attend the lectures or to indulge in the process of graduate education which, I have said, must become increasingly a self-education. He decided that he could learn more in 50 minutes by himself than any professor in Berlin could tell him in that same time. As a consequence, Kistiakowsky got such a good degree in the University of Berlin that Bodenstein wrote to me in 1926 saying, there is no future for George Kistiakowsky in Berlin. You would be foolish if you didn't bring him to the United States. We brought him to the United States.

I tell this story to insist that it ought to be a part of the graduate educational process that it be increasingly self-educational. The extent that you *prescribe* courses in the years of graduate work and to the extent that you make that course one in psychology, to that extent I would say you are disregarding whatever words of wisdom I can lay before you. Hence my plea is not for a course, or a graduate program in psychology, but rather those books of which we spoke this afternoon, that one can read in the quiet of one's own room, perhaps even with a low background of high fidelity music, say a Beethoven, or a Brahms, or a Caesar Franck symphony.

Somewhere in the training program for graduate students there should be room for what I might call a journal club, in which each graduate student, at least once each year, should tell his fellow graduate students, preferably in the presence of a liberal sprinkling of the faculty, of some new research or development in the field of his interest that he has read about and that he is ready to tell his fellow graduate students about. His fellow graduate students will give him a brutal assessment of his effort as a teacher, and the faculty might well supply a more charitable assessment of the effort. But that he ought to make the effort is something that I would insist upon as a necessary part of the graduate education program.

Let us turn now to a consideration of the relationships between pure science and pure engineering, and of the implications of these relationships for engineering education. In the domain of the inanimate, Michael Polanyi, who this

year has received the LeConte de Nouy Award for his two books, *Personal Knowledge* and *The Study of Man*, distinguishes two levels of reality. The upper level is composed of machines of every kind, the lower level is made up of the parts of those machines. To illustrate his thesis, he uses a watch. He shows that though you examine, however carefully, the separate parts of the watch in turn, you will never come across the principles by which a watch keeps time.

This may sound trivial, but is actually of decisive significance. For the study of inanimate objects constitutes the science of physics and chemistry and the study of machines forms the sciences of engineering, and we may now conclude, therefore, quite generally, that the subject matter of engineering cannot be specified in terms of physics and chemistry. Let loose an army of physicists and chemists to analyze and describe in utmost detail an object which you want to identify as a machine and you will find that their results can never tell you whether the object is a machine, and if so, what purpose it serves and how.

It follows from such considerations that "the knowledge of physics and chemistry is *ancillary* to the knowledge and understanding of operational principles," which Polanyi identifies with the science of pure engineering. It is to pure engineering that we must look to learn "how to achieve certain practical successes, of which pure science knows nothing." Physics and chemistry are essential to "determine the conditions in which the operational principles of machines will, in fact, operate successfully . . . physico-chemical examination of a machine can detect the causes of possible failures, of which pure engineering knows nothing."

Our acceptance of this view of engineering science in its relation to physics and chemistry has important consequences in our attitude towards engineering education. Engineering science on this view operates at a higher level of reality in the inanimate world than do physics and chemistry. To engage in pure engineering science it is necessary to *start* with a concept. In the physical sciences the concept may evolve from research randomly pursued. It is necessary to have a grasp of the concept of time before you can proceed to the making of a time machine.

We are justly proud of our magnificent achievements during the last three decades in pure science. Each year, as December approaches, the Nobel Committees in Stockholm provide us with additional confirmation of our success in physics and chemistry, in medicine and frequently also in literature.

Do our educational processes in engineering match our attainments in pure science? When one contemplates the mastery of operational principles that are involved in placing 3000 pounds of satellites into orbit around the earth, the placing of a lunar probe on target at a precise and predetermined time, the successful projection of a satellite round both Moon and Earth with all the hydrodynamic, mathematical and automation principles involved, we have, it would seem, cause for reflection and review.

The time has gone by when the engineer can design his machine or process by application of equations and formulae to be found in the appropriate Handbook of Chemical Engineering, Steam Tables, and the like. The handbooks cannot keep up with the swift pace of progress. Think, for example, of the new problems involved in the rapid removal of huge quantities of heat generated in small spaces, rocket and jet aircraft engines, nuclear reactors. The classical heat exchangers adequate for the chemical engineering problems of yesterday in the chemical industry, in the cooling of automobile engines, these required heat fluxes of the order of 50,000 Btu per hour per square foot. Now fluxes in the millions of Btu's are required, comparable, as Professor Westwater has recently pointed out, to the energy flux from the sun. Instead of the water pump, radiator and fan of the internal combustion engine, one uses boiling heat transfer. The cooling liquid boils away. "Ten years ago, calculation of boiling heat transfer was an art." It now requires knowledge of nucleation, the nature of solid surfaces, the study of bubble formation, stability and instability of waves and of viscous and turbulent flow. And Westwater tells us, appro-

priately enough, "information in all these fields is coming with a rush, and boiling heat transfer is becoming a science."

The heart of the educational process, in engineering as elsewhere, is the teacher-scholar relation. As, in the high school, it is the gifted teacher who imparts to the student college aspirations, so training for the new engineering science demands an intensified master-disciple relation. The new engineering teachers must be broadly educated men with humanistic assets for their tasks. Technologists will no longer suffice. These latter can provide the knowledge of what has already been achieved but what lies beyond the far horizon requires a new kind of faculty. As in the liberal arts and sciences, the teacher-scholar is imperative, alert to all the attainments of the past, alive also to consequences of the new knowledge now pouring into man's consciousness, and participating himself in the creation of that new knowledge. It is a formidable requirement. It will require a stimulated recruitment into the profession comparable with that which the Woodrow Wilson National Fellowship Foundation is seeking to provide in the liberal arts and sciences. The program should be positive. Something must be done, not talked about. A beginning can be made in the existing engineering faculties on whom lies the responsibility of reproducing their kind at an even higher level of capacity than they brought to their task. From four decades of experience in recruitment for university faculties I discern a pattern of quality growth. It lies in wise selection of able scientists and engineers, giving them, from the outset, favorable conditions for self-education and growth, wise counsel and advice from mature experience concerning their professional duties and activities. Perhaps, in such an effort at undergraduate, graduate and post-graduate levels in pure engineering, comparable with that achieved in the pure science in this country since World War I, there lies the solution to many of the anxieties which in these strenuous, competitive days, trouble us.

CO-OP DOCTORATES AT NORTHEASTERN

Starting in the fall of 1961 Northeastern University will offer new and distinctive programs leading to doctoral degrees in the fields of Chemistry, Physics, and Electrical Engineering based on its long experience in co-operative education.

In making the announcement, Dr. Asa S. Knowles, President of the University, stated that the formal course work of the first 2 years in the electrical engineering graduate program will be arranged on the co-operative plan to which the University has been committed for over fifty years.

Under this plan students alternate between periods of full-time study at the University and actual professional service in industry.

Candidates for the Ph.D. in physics and chemistry will be selected from among students who have completed 2-year programs of graduate study as teaching or research fellows in these departments.

Northeastern now enrolls approximately 100 students on co-operative 2-year programs leading to the degree of Master of Science. The new doctoral programs will require an additional 2 years of full-time resident study and research.

University of Kentucky—A Youngster Nearing 100

Host to ASEE in 1961

ASEE visitors to the University of Kentucky for the 1961 annual meeting will witness a 95-year-old "youngster" with growing pains, a progressive institution which will have combined the old with the very new by 1965 when UK holds its centennial activities.

Situated in the famed Blue Grass region known the world over for its thoroughbred race horses and tobacco production, the University through its multi-armed program extends instructional and intellectual commodities to its own borders and beyond to other states and countries. It combines a primary purpose of instruction with an equally important purpose of service to Kentucky's residents as chief ingredients of its educational program.

The Morrill Act of 1862 led to establishment of the land grant institution on February 22, 1865, when the Kentucky General Assembly chartered the Agricultural and Mechanical College and made it a part of the older Kentucky University, now Transylvania College. Under the Morrill Act, Kentucky was able to acquire 330,000 acres of public lands to support an A. & M. College. Thirteen years later, the Legislature established an independent Agricultural and Mechanical College of Kentucky, the support of which was to come from the state.

To provide a separate campus for the new institution, the city of Lexington donated its 50-acre fairground and park which, during the Civil War, had been utilized as a bivouac area for Union troops. Lexington and Fayette County contributed $60,000 for the construction of buildings, and President James K. Patterson, whose service to the University began in 1869, used his personal savings to supplement the building fund.

In 1880 three new buildings, "Old Main," now the Administration Building, a men's dormitory, and a home for the President, began rising on the old fairground-park site. All are still in use. The dormitory, now known as White Hall, is the home of the College of Commerce, and the President's old home is headquarters for the University Faculty Club.

Curriculum expansion began in 1887 with establishment of an agricultural experiment station. At that time the college included agriculture, civil engineering,

MEMORIAL HALL—Dedicated to men who died in World War I, this small auditorium with a magnificent electric organ graces most peaceful area of campus. A small amphitheater is located behind it.

SPINDLETOP HALL—The former private home on famous Spindletop Farm, now owned by the University of Kentucky, has been transformed into a spacious meeting hall for UK functions.

POPULAR MEETING PLACE—The Fine Arts Building at UK with its comfortable Guignol Theatre is site of many meetings, workshops and productions each year.

classical, scientific and normal departments. Two years later, a department of mechanical engineering was established, and courses in mining engineering were inaugurated in 1901.

A name change to State University was made in 1908 and a College of Law was established the same year. The department of agriculture became a College of Agriculture, the three departments of engineering became schools of engineering, and the classical, scientific, and normal departments were consolidated into a single College of Arts and Sciences.

In 1916 the school was given its present name, and a year later, with the beginning of the administration of President Frank L. McVey, began a transformation that was to lead to its current academic arrangement.

The three schools of engineering were merged in 1918 to form the present College of Engineering, a College of Education came into permanent existence in 1923, and a College of Commerce two years later. The Graduate School was founded in 1912 and put under direction of a full-time dean in 1924.

The University's eighth college was acquired in 1947 when the long-established Louisville College of Pharmacy was merged with UK. In 1954 the Medical Center was authorized and will include a College of Medicine, College of Nursing, College of Dentistry and University Teaching Hospital. All extended programs, including off-campus centers, were brought together under the Executive Dean of Extended Programs in 1957.

Since 1878 when the Agricultural and Mechanical College was separated from

ASEE HEADQUARTERS—This is Bowman Hall, headquarters for the 1961 ASEE meeting at the University of Kentucky.

Kentucky University, the institution has had but five presidents—James K. Patterson, 1878–1910; Henry S. Barker, 1910–17; Frank L. McVey, 1917–40; Herman Lee Donovan, 1941–56; and Frank G. Dickey, 1956 to the present.

William B. Munson of Astoria, Ill., received the first degree granted by the A. & M. College in 1869. Since that time the University of Kentucky has acquired approximately 32,000 alumni. From an enrollment of 190 students in 1866, the student population climbed to 10,157 in 1960. Another 4,000 persons were also receiving UK instruction through various other courses. In addition, UK has three contract teams in universities abroad, two in Indonesia and one in Guatemala.

Besides giving instruction to its student body, the University contributes to the welfare of Kentucky through research, experimentation, and public service, with several divisions and bureaus having been established specifically for those purposes.

Included in that group are the Experiment Station and the Extension Division of the College of Agriculture and Home Economics, the Bureau of Business Research, the Bureau of Government Research, the Bureau of School Service, the University and Educational Archives, the Bureau of Community Service, the University Placement Service, Radio Station WBKY, the Department of Public Relations, the Engineering Experiment Station, the University Computing Center, the Kentucky Geological Survey, the Child Guidance Service, the Industrial Psychological Service, and the Social Research Consultation Service.

The University is a small city in itself, having its own postoffice, bookstore, radio station, newspaper, printing plant, cafeterias, theatre, police force, and hospital. Including students, faculty and staff, the University community numbers about 18,000 persons.

There are 74 major buildings on the 706-acre main campus at Lexington. The campus farm contains more than 500 acres and the principal Experiment Station Farm, which includes historic Coldstream Farm, has 1,150 acres. The South Farm near Lexington includes 202 acres and there is an 89-acre poultry farm situated near Lexington. Sub-experiment stations at Princeton and Quicksand contain 600 and 200 acres respectively, and a forest reserve at Quicksand includes 14,800 acres. The University's Eden Shale Farm in Owen County has 934 acres, and 140-acre and 400-acre farms in Woodford and Mercer Counties are under long-term lease.

The University has five off-campus centers offering two years of college work. They are at Ashland, Henderson, Fort Knox, Covington and Cumberland.

Total fixed assets of the University, including land, buildings, and equipment amount to approximately $78,000,000. Campus projects now in various stages of planning or construction will cost about $12,000,000. New projects include, besides the Medical Center, a science-physics building, women's residence hall and central dining area, Commerce College building, addition to Student Union Building and addition to the main library. Two other projects with which the University will have a direct tie-in include the Spindletop Research Institute and the Agricultural Research Center, both state projects to be located on University property at Lexington.

UK students come from all of Kentucky's 120 counties, 43 other states, the District of Columbia, and 40 foreign countries and U. S. possessions. About 88% of the students are Kentuckians.

Headquarters for the ASEE meeting will be in Bowman Hall, men's residence hall.

SEE YOU IN LEXINGTON JUNE 26–30

On University Courses in Materials for the Engineer

WILLIAM R. MICKS

Aero-Astronautics Department
The RAND Corporation

Importance of Materials

The subject of materials courses for the undergraduate engineer is extremely important. One has only to examine a few of the engineering end-items, particularly those near the frontiers, to recognize the key roles played by materials. Indeed, the level of capability and efficiency of almost any engineering hardware is limited by the success with which materials are employed and by the basic limitations of the materials themselves. One can also observe a number of serious problems created by a less than adequate employment of materials in certain engineering products. And in addition to recognizing these more obvious problems, one gets the uneasy feeling that there have existed, and continue to exist, a number of unrealized, or delayed, opportunities for significant improvements in engineering systems where these deficiencies could be related to an inadequate treatment of the role of materials in the various stages of conception and design of the systems.

If one examines the engineering failures, defined in terms of hardware that could not be made to operate in the manner intended, or that had to undergo tremendously expensive redesign and repair, one can get a number of indications concerning the kind of information and knowledge that seems often to be lacking in the design engineering function responsible for creating new hardware systems. And here I think the engineering colleges should adopt the positive attitude of viewing this situation as an opportunity of significant proportions, in addition to viewing it in terms of a strong and direct responsibility to the students and to the country. I doubt if there exists another single area having as great a leverage factor on end-item capability and economy as has the area of materials and their proper employment.

Factors Relevant to Course Content

However, to identify and study the interface between the subject of materials and engineering endeavor as a whole, it is desirable to consider briefly a basic philosophy of approach that perhaps is far too little recognized, encouraged, or taught as an essential part of an engineering curriculum. This philosophy involves the creative or synthesis element that is the fundamental essence of those engineering activities that afford progress. I would like to discuss this philosophy in more detail in a moment.

There is another factor that should enter into the deliberations concerning materials courses for engineers in that this factor represents perhaps one of the most significant changes in the engineering approach and environment that has come along in the last 25 years or more. This is the increasing frequency of the practice of designing broad engineering systems [1] as single units. This is differentiated from the design of separate specialized components that are considered more or less in isolation from one

Presented at the 68th Annual Meeting of the American Society for Engineering Education at Purdue University, June 20 to 24, 1960.

[1] An example of a system is the ballistic missile system comprising the missile itself and its many elements of ground support such as transport, checkout, and launch equipment. It is interesting that the ground support represents most of the total system cost.

another until the final stage, at which time the best-matching components are chosen and put together with the hope that the over-all result will operate at reasonable efficiency.

Still another factor to be considered is related to the question of research. Although I do not plan here to consider materials research, since it is anticipated that the actual prosecution of materials research would be carried out by materials specialists and not by engineers, I do want to point out that most of the various factors to be mentioned here are integrally related to the processes of deciding about research—formulating research programs, guiding and evaluating these programs, and setting proper research goals. It has become clear that in the management of materials research and development there is a vital need for including as an integral part the consideration of the design or synthesis point of view, which we will discuss next.

The Engineering Function

It is perhaps relevant to a clear definition of the engineering function to point out an important distinction of a general nature between engineering and science. This essential difference, as I see it, is summarized by the words "analysis" and "synthesis," the latter being the essence of the engineering function. Science is thought of here as the process of discovering new knowledge about nature; engineering is the process of creating new "things" through selective application of this knowledge. Whereas scientific activity has goals and motivations oriented toward discovering and understanding (analyzing) various phenomena in nature, the engineering goal is that of creating (synthesizing) a system to perform a specified job. Obviously each of these activities is an indispensable link in the chain of human progress; however, their differences should be clearly recognized, particularly when assessing their implications for engineering curricula.

To illustrate the nature of the difference between the analysis and the synthesis approach in engineering, let us consider a simple example taken from the subject of strength of materials. Most textbooks on this subject derive the familiar Euler equation for column buckling,

$$P = \frac{\pi^2 E I}{L^2} \qquad (1)$$

where L is the length of a pinned-end column, E is the modulus of elasticity of the material, I is the moment of inertia of the cross section, and P is the load at which an elastic column will buckle.

Included with the treatment of this subject one usually finds problems of the type: Given a column of specified length, cross section, and material, at what load does it fail? The equation given above can be used to calculate this failing load. Please note here that this equation, in essence, is an *analysis* equation. It describes a certain phenomenon in nature—it predicts the load at which a given column will buckle.

However, this is quite the opposite of the problem encountered by the engineer, whose job is to synthesize or design a column to do a specified job. The engineer's problem might be stated: Given a compressive force P to be transmitted over length L, what material and what cross section gives the "best" column for the specified set of side conditions. If the designer recognizes the basic nature of his problem, he rewrites the above equation in the form tailored for design, which tells him the relationships between the design quantities he knows to start with and the result he wants to determine, namely, the maximum stress that can be attained in a column for any cross section and any material:

$$\sigma = \frac{P}{A} = \left[\pi^2 E \left(\frac{I}{A^2}\right)\left(\frac{P}{L^2}\right)\right]^{\frac{1}{2}} \qquad (2)$$

where A is the cross-sectional area and σ is the maximum attainable stress. The factor I/A^2 measures the efficiency of the cross section for any generic shape (independent of size), and thus guides the designer's choice of cross section. The factor P/L^2 defines the structural job that his column must perform, which has been specified to begin with. The load P, together with the stress σ, defines

the required area. Since he has already chosen a shape (I/A^2) and a material (E), the designer can immediately calculate the size of cross section required.

Although Equations (1) and (2) are identical mathematically, they are opposite in function. For simplicity we have used here the elementary case of purely elastic behavior, but if we include consideration of the inelastic range (as we generally must), by substituting the tangent modulus for the elastic modulus, Equation (1) becomes almost unworkable for design, whereas Equation (2) handles this complication very easily because it is a design equation. In almost every case where the designer attempts to use an analysis equation for design, he is forced into a cut-and-try procedure of some kind. (It should be noted, however, that the analysis equation for describing behavior is an essential prerequisite to the writing of the design equation, and illustrates by analogy the dependency of the engineering function upon the scientific function.)

To summarize this point we have attempted to illustrate, by means of a very simple example, the basic difference between the analysis approach and the synthesis (design) approach. The analysis approach describes a phenomenon of some sort, and is used in the above case to predict the conditions for occurrence of this phenomenon. Of a basically opposite nature is the design approach, in which there is specified a job of some sort and the designer's task is to define the element that will perform this job in the most efficient manner.

It is the basic methodology of this design approach that I feel is largely lacking in many of today's engineering curricula. Most of the undergraduate engineering curriculum is devoted to the analysis aspects of the subject matter covered—almost exclusively so in the science courses and in the theoretical areas such as fluid and solid mechanics. As was pointed out, these form an essential first step, and as such they represent a very necessary part of the engineering curriculum. However, today one frequently hears somewhat alarming reports of a growing trend to make these analysis aspects also the last step by the gradual elimination of more and more of the engineering design courses. In my opinion such a trend would be very unfortunate indeed, since these design courses often are the only courses that even introduce the student to the subject of just what engineering is all about.

Materials Behavior Instead of "Properties"

If we now look for the implications of the design function for the preferred characteristics of materials courses we see that the most important need for engineers is the study and understanding of behavioral relationships in materials. If the engineer can know how his materials will behave under the various design situations, and if he is familiar with the fundamental mechanisms that control this behavior, he then has the basic information from which to forge his design tools. He should not have his time taken up by study of the so-called "properties" of materials.

To illustrate the importance of differentiating between "properties" of materials and "behavior" of materials let us consider the concepts of "brittleness," "ductility," and "strength" in materials. The use of these terms without qualification (which is how they are generally used) has been a major stumbling block to progress in the understanding of materials behavior. Our basic mistake is made when we attempt to pin these labels on the material itself, and thereby imply (wrongly) that brittleness and ductility are intrinsic properties of the material. We do this even though we know full well that any material will flow plastically if the shear stress is high enough relative to the normal stresses and even though we know that we would get "brittle" behavior in butter under the condition of equal tri-axial tension. And of course the effects of temperature and time will also appear anomalous if we try to define materials as brittle or ductile. The point here is that the labels should not be attached to the materials but rather to their *behavior*, with the understanding that almost any type of behavior is possible in any material and

that the behavior is the response of the material to a given set of conditions and circumstances. Likewise "strength" is not a property of a material but rather a response of the material to a specified set of conditions. The harmful effect of this kind of semantic confusion on the future thinking and progress of our engineering students cannot be overestimated.

Course Content

Ideally, the subject matter for an engineering course on behavior of materials should include a study of the relevant aspects of the internal characteristics of the material and of the mechanisms of behavior as they are influenced by these internal characteristics and by the applied conditions to which the material is subjected. Internal characteristics would include such things as atomic structure, atomic forces, and micro-structure. Deformation mechanisms on the atomic level would include elastic deformation, slip deformation, and creep—as they are influenced by internal structure and by externally-applied conditions of stress (including multi-axial stress in the inelastic range), temperature, and time. Also desirable here is at least a brief consideration of the influence of manufacturing factors on structure—factors such as heat treating, extrusion, rolling, etc. A study of deformation mechanisms on the microscopic level in polycrystalline and polyphase materials is desirable as well as a study of the effects of anisotropy on behavior characteristics in different orientations. Finally a study of macroscopic mechanisms of deformation (brittle fracture, ductile failure, fatigue, etc.) is required to complete the picture. I list these items with the unhappy awareness of two factors: One is the constraint on time available for covering this subject matter; the other is that we have not yet developed an understanding of some of these topics.

In areas where our knowledge is incomplete it is important that the student's curiosity be courted by telling him about the important unsolved problems, and that his faith in our honesty be maintained by our frank statement of the state of ignorance existing in certain areas of materials behavior. He should be made aware of what we do not know, if for no other reason than that this is the first and foremost area where he will get in trouble in later engineering endeavors. Further, his spirit of adventure should be aroused wherever possible by exposing him to the many interesting and exciting anomalies that have been observed in material behavior under certain circumstances—anomalies that hint of important undiscovered opportunities and perhaps that might beckon to a special few.

As the limits of our technological capability are continually extended, many of our traditional materials approach their ultimate capability, and new materials must be brought under consideration. For reasons of capability, as well as economics, it is necessary that the engineer be knowledgeable in the area of nonmetallic materials as well as in the area of metals.

Although this may appear to enlarge greatly the amount of material to be covered, a number of very capable materials scientists and professors are now pointing out that a new compensating factor is beginning to operate as a result of increased knowledge of a fundamental nature. It is not generally enough recognized, they say, that when we get down to the fundamental level in materials, the many apparently great differences between various classes of materials tend to merge and become merely different values of a few fundamental quantities. In other words, if we can teach the fundamentals of materials, we can utilize course time much more efficiently, we can cover much more ground, and we can at the same time reap the many benefits of fundamental understanding. If our current state of knowledge now makes this possible, we should spare no effort to put this knowledge to use.

The Trend Toward System Design

Earlier I mentioned a certain trend toward the practice of designing systems as a whole in which interrelationships of the system components were included

as an integral part of the design considerations. For example, in the creation of a flight vehicle system we find the civil engineer working on civil engineering problems involved in the design of launching facilities and ground support equipment, but with the boundary conditions for his design being specified by the operational characteristics of the flight vehicle. Likewise we find mechanical engineers working on mechanical equipment but again with side conditions set by the over-all system requirements. The same is true of other engineering specialties that might be involved in the design.

The aeronautical engineer who designs the vehicle cannot afford to ignore the implications of his design for requirements in the other portions of the system if the system is to be efficient and economically feasible. No one engineer is working exclusively in his specialty—he is working on the creation of a system. The more he limits his field of vision to his own specialty, the less efficient and capable will be the over-all product.

On Specialization

What this trend implies is perhaps a need for not restricting the student's field of vision by too much specialization. I am not against specialization in the sense that it implies greater depth; I do oppose specialization in the sense that it implies greater narrowness and limitation in vision.

I believe that part of the answer to the problem of specialization lies in teaching fundamentals to the maximum extent possible, as was mentioned previously. When we go to the depth sufficient to reach the fundamental level, there is little question of specialization and we immediately effect a significant economy in time. Also, if we would concentrate more on teaching the student about the process, or methodology, of engineering itself, there would be much less need for specialization. It seems to me that the primary undesirable aspect of specialization is that it attempts to remedy a basic deficiency in fundamentals and in method by substituting more "facts," which are really only restricted observations. Where we can combine the teaching of method with the teaching of fundamentals we can greatly ease the pressure calling for more and more different and specialized courses.

My assignment for this meeting was to talk on the requirements of the aeronautics/astronautics field for courses in materials. By now the point must be clear that I see no unique requirements here for the undergraduate engineer. Rather I see a general requirement calling for concentration on the engineering method and on fundamentals to the exclusion of demands for specialization. I would also presume to extend this opinion to the other branches of engineering.

The Materials Scientist as a Partner

In conclusion I would like to add one further thought—that somewhere in his engineering materials course, the engineer should be exposed to the observation that the most successful engineering endeavors involving materials to any extent are those in which the engineer works together with the materials expert as a partner. It is to the engineer's further advantage if he defines his problem in such a way that there is sufficient flexibility and opportunity for the materials expert to suggest improved means for solution. In cases where the engineering designer defines his problem too narrowly, or neglects the opportunity to work with the materials specialist, we observe that his product often suffers from unnecessary problems and from lost opportunities to create a much superior engineering product.

ASEE ANNUAL MEETING, LEXINGTON, KENTUCKY, JUNE 26–30, 1961

Teaching Design for the Rest of the Twentieth Century

PAUL F. CHENEA

Head, Department of Mechanical Engineering, Purdue University

Since the end of World War II steady progress has been made in the engineering curricula in the United States. This progress has been primarily in the area of the engineering sciences. Due to the additional emphasis placed on the engineering sciences during the war and the impetus of the Grinter Report, instruction in the engineering sciences has been continuously upgraded during the past 15 years. This progress has been very important and has done much to modernize current engineering educational programs.

Progress in the teaching of engineering design, however, has not kept pace, and the current philosophy, procedures and practices in the teaching of engineering design have not appreciably improved from those of the nineteen-twenties or thirties. In fact, we may have lost some ground. Today, design courses do not generate the excitement, motivation and interest on the part of the student that the engineering science courses do. Thus, they do not compete with other offerings in the engineering curriculum. These events have concerned some engineering educators and at many institutions considerable thought and study have gone into the problem of teaching engineering design. The faculty of several institutions have concluded that this may be an area of knowledge that cannot be successfully taught and hence have taken steps to eliminate an experience in design from the student's program. This has caused some engineering educators to become confused about the difference between science and engineering. Engineering education programs without a design experience become applied science programs and whereas they may graduate some young men who eventually become good engineers, they are not designed specifically to educate engineers. It is the design process which characterizes engineering, and without some appreciation and background in the philosophy and compromises of design, the student can hardly be called an embryo engineer.

Given at the Annual Meeting of the ASEE June, 1960. Recommended for publication by the Mechanical Engineering Division.

The Tradition

What then are we to do about engineering education in the area of design? To understand the problem and to bring it into sharper focus, it is worthwhile considering what is now done and what has traditionally been done in the teaching of engineering design. Within the realm of mechanical engineering it has been common to offer courses in machine design as the primary design experience. Courses in machine design have many disadvantages, not the least of which is that they assume almost at the start that such areas of knowledge as thermodynamics, heat transfer, electrical circuits, electrical fields, automatic control, fluid mechanics, and computer technology do not exist. Clearly, this is a very narrow look at engineering design. Further criticism to the current approach to teaching design is that most courses are aimed primarily at the introduction of the student to some of the kinds of calculations and some of the kinds of thought processes which a *current designer* performs when he does design. There is, however, very little of the decision-making process in the usual design course. In general, it appears that there are at least three things wrong with this approach: 1) Current design is unfor-

tunately *current* and there is very little guarantee that the detail processes which characterize today's design calculations and procedures have much permanence in the future. 2) Unfortunately, we are not even current with today's industrial practice. It is impossible to be up-to-date when the object is to copy and hence we lag from 5 to 10 years behind current industrial practice. 3) Finally, one of the most serious disadvantages in teaching current engineering design is that current design practice is a product of the attitude and background of current engineering designers. Today's engineering designers, in the main, have a formal education that is 15 to 25 years old coupled with 15 to 25 years of actual engineering experience. This background leads today's practicing engineer to approach his problems in the way he does. Unfortunately, the background of most of today's engineering designers has about as large an impedance mismatch with the student's background and experience as it is possible to imagine. The engineering student's education, particularly in the engineering sciences, is much more modern and rigorous. He is better equipped than the average practicing engineer of today in scientific areas. In addition, he has had very little experience, if any. Consequently, design taught from the standpoint of why industrial designers do what they do today is primarily a business of showing the student how he would think and act if he didn't have his education, but had one which was semi-obsolete coupled with a good deal of practical experience.

Using the Sciences

It would seem reasonable to approach engineering design from the standpoint of showing the student how to exploit his superior formal education in design situations. Clearly, the student will gain experience as he goes through life, but the background with which he must start his career is his formal education. Hence, I would strongly advocate that all design courses begin by showing the student how to apply the engineering sciences to the problems of synthesis and optimization and let him add his own experience to this later, rather than to try to pass on an experience that was gained by other people during the past decade or two in a quite different economic and technological environment.

In addition to the question of applying the student's modern education to design problems, there comes a question of what is the fundamental discipline of design. Many engineering educators will insist that the primary characteristic which distinguishes engineering design from other activities of engineering and science is the fact that it involves synthesis. I doubt that synthesis is the distinguishing characteristic of design, although it certainly is a very important aspect of design. After all, the pure mathematician is interested in synthesizing new areas of mathematics and the chemist is interested in synthesizing new compounds. The value of inventiveness and ingenuity plays just as big a role in pure science and the arts as it does in engineering design. Rather, I would propose that the distinguishing characteristic of engineering design is the continual search for a better way—not just a way—preferably an optimum way of accomplishing a given job. Engineers usually try to maximize some desirable attribute or minimize some undesirable attribute or a combination of these. Thus, the engineer is continually seeking more economical, quicker, more reliable ways of building devices and organizing operations as he carries out his design and engineering functions.

I believe that optimization and optimization techniques are the central discipline which ought to provide the solid core to engineering design. Around this, of course, will come all the peripheral problems that are associated with design such as the fact that one never has enough information, the problem of deciding precisely what it is that one is trying to do, the difficulties of anticipating the future inputs and loads as well as the problems associated with production. Nevertheless, it is the seeking of an optimum of some kind that is the important central discipline, recognizing, of course, that this search is to be carried out as best one can under conditions

which are never ideal and which are never completely stated. Hence, optimization techniques, in my opinion, should be looked upon as the fundamental backbone discipline of engineering design.

How It Can Be Done

It may be asked, how can one do this? Actually it does not appear too difficult. If the teaching of design starts in the junior year, for example, one should look to see what the student's background is at this time so that this can be exploited in the first design course. The student's background usually consists of about two years of mathematics including some differential equations, an introduction to physics and chemistry, a year of engineering mechanics, and probably a semester of thermodynamics. It should also contain a year of electrical circuits but frequently doesn't. This background essentially adds up to just one thing. The student is reasonably well prepared to analyze and discuss the design of lumped-parameter systems of an electrical, mechanical and thermal nature. At this stage of his education he has not had any field theory and consequently field problems cannot be brought into the design complex. This means he is not ready for component design which usually involves field considerations.

Let's consider for the moment the problem of optimizing lump-parameter systems. Of course, to optimize a system one must decide what it is he is trying to maximize or minimize. In engineering it is frequently production cost which is to be minimized, or reliability which is to be maximized, or performance which is to be maximized, or weight which is to be minimized, etc. These functions must be established in each case and it must be determined how the parameters of the various systems which technically could do the job enter into the function to be optimized. This is essentially a problem in analysis. How do the parameters affect the system overall performance or cost? Having arrived at such a pay-off function, one could proceed in the following way. I would first show the student that in the simplest case the problem of finding an optimum set of parameters is really a problem of differentiating the pay-off function with respect to the parameters and setting the various equations equal to zero. The solution of these equations gives the optimum parameters. This is the simplest possible design problem. After the student has developed some feeling for this process one could then point out that this is usually done in the face of constraints. In the main, these constraints are equations which must be satisfied by the parameters. They define the domain of acceptable solutions. The technique for handling this problem is, of course, Lagrangian multipliers and this kind of mathematics is simple enough to be understood by a junior without difficulty. Thus, the student would develop a feeling for the determination of optimums in the face of constraints which are equalities. Then one would point out that many of the engineer's constraints are in the form of inequalities. Some quantity must not exceed a certain value or something must happen in a given time, etc. Such problems are really problems in linear programming and in its simpler form this is not difficult mathematically. It can be well understood by a junior engineering student.

Having discussed with the student problems of optimizing with various kinds of constraints, I would then proceed to point out the other features which enter into the optimization problem. One of these is that many of the pay-off functions have multiple values. Hence, one has to seek out all optimums and compare one with the other to find the best solution. One can go further. Frequently the engineer is interested not in simply maximizing or minimizing one pay-off function, but he has several, and he is looking for a trade-off point where the overall situation is the most desirable one. Thus, he may be trying to minimize weight, but he is willing to pay only a finite price for minimizing weight. In this way the notion of trade-off enters naturally and very properly into the design process.

Finally, in the first design course, the student should be made aware that the

engineer never has a completely analytical problem. There are always many features of the problem which can only be described empirically. Thus, the problem reduces to the search for optimum situations in the midst of empiricism. These problems are very difficult to do analytically, if not impossible, but they are very simple problems, in the main, on digital and analog computers and so I would terminate the first engineering design course by showing the student how to ask the computer to search out optimums in the midst of empirical situations.

As outlined above, the object of the first course in design is an exercise in the discipline of optimization. This is a clear-cut hard core that would provide an excellent background and a good vehicle for the generation of the right attitude in engineering design. With this background the student could proceed to more difficult problems in the senior design courses.

To speak of a senior design experience for the moment, the principal new thing which the student has at his command at this time is some background in field theory. By this time he has had some introduction to fluid mechanics, heat transfer, stress analysis and possibly electro-magnetic theory. Thus, he can be introduced to the optimization of field problems and particular optimum geometries for fields. In other words he is ready for component design. The mathematical techniques involved here are well known. These techniques are partial equations and the variational calculus. In their elementary form they are perfectly capable of being understood by the undergraduate student. In addition to this knowledge, the student should by now have some background in probability and statistics. Thus, one can point out that the inputs and loads on a system are rarely known other than as random or stochastic variables. The materials of which he builds his system are rarely precisely uniform but have properties which vary and can only be described in terms of mean values and standard deviations. The production tolerances which are an essential part of economic production are such that no two systems which are manufactured will be precisely the same and hence the component parameters are also stochastic variables. The problem of optimization becomes one of looking for the most probable optimum in a stochastic system.

Finally, I would insist that the senior be introduced to the laboratory. Experimental design is an important part of design philosophy and I would send him to the laboratory to optimize an actual physical system, preferably one which involves mechanical, electrical and thermal components. Thus, I would insist that he determine the characteristics of the components of his system experimentally and that he determine how the adjustment of the parameters in this system affects their overall performance. Then he should use this information to formulate a theory for the total system behavior and simulate this system on a digital and analog computer. Finally he can seek out as best he can in the simulated system a set of optimum parameters. He would then go back to the real system and adjust it so that it has these optimum parameters and investigate on the actual physical system the performance in the neighborhood of what he hopes is an optimum. Thus, he would complete the design cycle and see how well he can predict performance and particularly how well he can look for the optimum situation. This is the backbone of engineering design.

Such an approach to engineering design has nothing to do with current practices and mispractices. Instead, it is aimed solely at the problem of showing the student how to apply his superior education in the engineering sciences to the design problem of the future. This will provide him with a background which he can continually enrich as he gains experience in actual design problems in the years to come.

Many will say that design taught in this fashion will not equip the student to fit into a design group immediately upon graduation and this may be true, particularly in those industrial enterprises that have not yet recognized the impact

of science and modern technology in their engineering activities. But how far into the last 40% of the twentieth century will this situation exist? I think such industries will learn to capitalize on science and modern technology. I would even say they will be forced to recognize all pertinent new knowledge and techniques if they are to prosper. Thus a graduate with a better design background may be needed more, not less, by these organizations than by the more progressive industries.

Others will point out that the techniques of optimization under many conditions are very difficult, indeed, they are not known at this time. In fact some of these problems border on dynamic programming, game theory and statistical decision theory, which are valid and respected areas of research for mathematicians. I would point out, however, that in no other area of engineering education have we waited until it was a closed book before we exploited what was known in the undergraduate program. In fact the current healthy state of the engineering sciences is primarily due to the active pursuit of graduate research which continually feeds new ideas into the undergraduate program. Perhaps we could generate for the first time some real research in design techniques and thus have a graduate program in design that would be worthy of the name. In fact universities might become the leaders in this area instead of the blind copiers of the past.

I am sure that there will be those who will say that the current teachers of engineering design are not equipped to teach such courses. Unfortunately, this is true in many instances. However, I would submit that our younger staff members are better equipped to approach design in a progressive forward looking fashion than they are to pass on an experience and philosophy which they too obtained second hand.

Education for engineering design must be made a vigorous part of our engineering education or it will perish. If it perishes then there is no need for engineering education.

MICHIGAN STATE TO ADVISE IN INDIA

Two Michigan State University officials have left for India to pave the way for a team of engineering-education advisers who will follow later this year. Michigan State was recently awarded a $695,000 grant from the International Cooperation Administration to provide technical advice and assistance to the government of India.

The university will assist in establishing teacher-training programs in engineering at Guindy College of Engineering in Madras and Poona Engineering College at Poona.

Dean John D. Ryder of MSU's College of Engineering left for India Jan. 3 and will return to the East Lansing campus March 17.

Nine specialists from Michigan State are called for in the initial phases of the project in India.

Michigan State's engineering-education assistance is similar to programs being carried out by the Universities of Wisconsin and Illinois, each of which is also working with several institutes in India.

Professional Graduate Study in Engineering

MORROUGH P. O'BRIEN

Dean Emeritus, College of Engineering, University of California, Berkeley, California; Consulting Engineer, Defense Electronics Division and Flight Propulsion Division, General Electric Company

Engineering occupies an anomalous position in most American universities. Graduate study in engineering has been strongly influenced by this situation and has been deflected away from a professional emphasis comparable with that characteristic of the study of law or medicine. Discussion of professional graduate study in engineering requires a review both of these circumstances and of the place of the engineer in an industrial society, of the past record of engineering education, and of the obligations of an engineering school to its students, to the profession, and to society.

As to the general situation affecting engineering education, an incisive view written regarding British universities but increasingly true of the larger universities in the United States, is that of Sir Eric Ashby.[1]

> . . . pure scientific research is akin to other kinds of scholarship: it is disinterested, pursued for its own sake, undeterred by practical considerations or public opinion. There is no great divergence between the attitude of the physicist toward the concept of entropy and the attitude of the philosopher towards the concept of virtue. But teaching and research in technology are unashamedly tendentious and their tendentiousness has not been mellowed (as it has for medicine and law) by centuries of tradition. Technology is of the earth, earthy; . . .; it is under an obligation to deliver the goods. And so the crude engineer, the mere technologists are tolerated in universities because the State and industry are willing to finance them. Tolerated but not assimilated; for the traditional don is not yet willing to admit that technologists may have anything intrinsic to contribute to academic life. It is not yet taken for granted that a faculty of technology enriches a university intellectually as well as materially.

The independent engineering schools include such large faculties in science and the humanities, that these comments are also valid for them in some degree.

In short, engineering is not quite "respectable" academically. The engineering schools have, I believe, encouraged this attitude in a number of ways. Primarily, they have been uncertain about their proper objectives. This uncertainty has led to compromises in their plans, especially at the graduate level, between the preparation realistically desirable for professional practice and the appearances deemed necessary to satisfy the "standards" of the non-engineering faculty. The scientific phase of graduate study in engineering—and a very desirable phase it is—has encountered little difficulty because it is, in fact, a branch of science and therefore respectable; but this acceptance of a parallel program does not meet the need for *professional* studies beyond the traditional four-year bachelor's degree program. It is the purpose of these notes to discuss this need and to suggest the general features of a program.

A recent report entitled "The Pursuit of Excellence: Education and the Future of America," [2] made this statement:

> There is no more searching or difficult problem for a free people than to identify, nurture and wisely use its own talents. Indeed, on its ability to solve this problem

[1] *Technology and the Academics*, Macmillan, 1959.

Presented at the ASEE Annual Meeting, June, 1960. Recommended by the Graduate Studies Division.

[2] The "Rockefeller Report" on Education. Rockefeller Bros. Fund. Doubleday, 1958.

rests, at least in part, its fate as a free people. For a free society cannot commandeer talent: it must be true to its own vision of individual liberty. And yet, at a time when we face problems of desperate gravity and complexity, an undiscovered talent, a wasted skill, a misapplied ability is a threat to the capacity of a free people to survive.

But there is another and deeper reason why a free nation must cultivate its own human potential: such a task reflects the very purposes for which a free society exists. If our nation seeks to strengthen the opportunities for free men to develop their individual capacities and to inspire creative effort, our aim is as importantly that of widening and deepening the life purposes of our citizens as it is to add to the success of our national effort. A free society nurtures the individual not alone for the contribution he may make to the social effort, but also and primarily for the sake of the contribution he may make to his own realization and development.

To meet the needs of society for professional practitioners, colleges and universities offer preparation for nearly all of the established and recognized professions. With a few exceptions, the number of practitioners made available depends not upon the aggregate capacity of these institutions but upon the preference of the students, freely exercised on factual, emotional, or other grounds.

Engineering and Society

During the first century of their existence and until the end of World War II, the engineering schools of the United States played an important role successfully in "widening and deepening the life purposes of our citizens" and adding "to the success of our national effort." The programs of study were realistically matched, in the aggregate of all programs in all schools, both to the preparation and abilities of the students admitted and to the need of our society to fill a broad spectrum of technical positions in research, development, design, teaching, manufacturing, construction, technical sales, and many other functions. The graduates were non-uniform in native ability, technical knowledge, and personal traits—but the opportunities open to them were equally diverse and they were notable as a group in meeting what is, I believe, the first requirement for good citizenship—the capacity to earn a living. Perhaps these graduates were deficient in civic consciousness, cultural background, and scientific depth and, perhaps, the schools should have corrected these deficiencies—but, in judging this matter, considerable weight should be given to the facts of the record.

The record of the engineering profession in this country is one of outstanding success—for which no apologies need be made—and one about which a profession less modest might do a great deal of boasting. Its greatest period of achievement was during the last war when America's capacity to develop arms and equipment was the wonder of the world—and the bulwark of the free world.

The place of engineers and engineering in our society and, particularly, the part which engineering plays in sustaining and enhancing our national productivity and standard of living is a subject which deserves especial attention during this period of international stress. We are engaged in two conflicts—one military and the other economic—in which engineers play a vital role both in supplying the materiel for our defense and in strengthening our economic position. We might win militarily but in doing so destroy our economy; on the other hand, too great a concentration on normal affairs to the neglect of defense will leave us open to aggression. Skillful use of our resources in men, money and materials is required for ultimate success. The engineering schools must continue to provide an adequate number of well-prepared graduates to carry on this essential work.

A good measure of the over-all effect of the development of machines and the use of power to aid men in their daily lives is provided by a study called the "Needs and Resources of America," which presents an analysis of the change in productivity in the United States since 1850—that is, in the amount a person earned per hour of effort and the parallel change in the use of manpower, animal power, and machine power. Real income, averaged over the country and including all industrial workers, was 27¢ per hour

in 1850, measured in 1940 dollars. By 1900 hourly income had gone up to 56¢ an hour and by 1930, to 82¢ an hour. These figures are all in terms of the same 1940 dollars. The extrapolated figure for 1960—this study was made some years back—was $1.61, an increase by a factor of six times in the return per hour of effort since 1850. This forecast apparently has been realized. During the same period of 1850 to 1940 the average work week was reduced from 73 hours to 43 hours. Through the design of structures, circuits, machines and processes, and the design of systems and plants, engineers provide the major means by which the productivity of labor is increased and the general standard of living raised. Many similar compilations might be cited bearing on this point.

Engineers should understand this function which they perform in society and should be aware of, and as a group work to influence, the policies, laws, and public attitudes which tend to expand or circumscribe their activities.

Engineers are not alone responsible for our steady increase in productivity—but engineering is the major profession involved whose primary objective and central activity is this increase. Mere duplication of existing machines, structures, circuits and processes could be accomplished without professional engineers.

The history of the Manhattan District has sometimes been cited as giving evidence that American engineering was somehow deficient. In this connection it is fair to say, on the one hand, that appraisals by American physicists showed that a large majority of the ideas basic to the A-bomb development were of foreign origin, or originated with scientists of foreign education; the United States made its major contribution to this project through its technology. To quote a concise summary of this situation [3]:

> Following the initial impact of the discovery of the release of atomic energy, it took almost a decade to bring realization that the achievements of the Manhattan District Project and early work under Atomic Energy Commission auspices represented no striking, basic scientific-research accomplishment by this country but rather the application on an enormous scale of its great technological know-how and capacity.

Foreign observers of the American scene have noted the close relationship of engineering to our productivity and our standard of living. At the M.I.T. Mid-Century convocation, Winston Churchill commented on this relationship as follows:

> We have suffered in Great Britain by the lack of colleges of university rank in which engineering and the allied subjects are taught. Industrial production depends on technology and it is because the Americans, like the pre-war Germans, realized this and created institutions for the training of large numbers of high-grade engineers to translate the advances of pure science into industrial techniques—it is for this reason that their output per head and consequent standard of life are so high.

These comments were made at a time when Great Britain was deeply concerned about the slow increase in its productivity. A number of thorough studies of this problem had been made generally leading to conclusions represented by the statement of Mr. Churchill. To quote one of these studies:

> The above broad survey, crude as it is, leads inescapably to the conclusion that for a given (world) level of fundamental scientific knowledge, a major influence on the long-term trend of productivity is the rate at which applied scientists and engineers are trained and used in industry.[4]

Going back a little farther in history,[5] the dominant industrial position of Great Britain in the mid-nineteenth century was challenged successfully by France, Germany, Switzerland, Holland and Sweden, which had been predominantly agrarian economies, through the establishment of independent technical schools to provide the engineer-managers essential to industrial expansion. Great Brit-

[3] Paul Gross, "Some Aspects of Federal Support of Higher Education," *Journal Association of Graduate Schools*, October 27, 1960.

[4] Sir Ewart Stewart, "High Technological Education and Productivity"—*American Scientist*, April 1951.

[5] See "Technology and the Academics" by Sir Eric Ashley.

ain's industry had grown up with substantially no encouragement or support from its educational institutions.

Much more might be said regarding the role of engineering in an industrial society and about the remarkable achievements of the engineering profession in the United States. In view of these obvious consequences of engineering activity, it is remarkable that there has been so much debate over even a definition of the nature of engineering and of the term "engineer." This Society has provided the forum for much of this debate and I hesitate to take time for additional comment now, but I find that I must do so in order to make clear my later conclusions.

In 1832, Sadie Carnot concluded his classic work on the second law of thermodynamics with this paragraph, which reads in translation as follows:

> We should not expect ever to employ in practice all the motive power of the combustibles used. The efforts which one would make to attain this result would be even more harmful than useful if they led to the neglect of other important considerations. The economy of fuel is only one of the conditions which should be fulfilled by steam-engines; in many cases it is only a secondary consideration. It must often yield the precedence to safety, to the solidity and durability of the engine, to the space it must occupy, to the cost of its construction, etc. To be able to appreciate justly in each case the considerations of convenience and economy which present themselves, to be able to recognize the most important from those which are only subordinate, to adjust them all suitably, and finally to reach the best result by the easiest method—such should be the power of the man who is called on to direct and coordinate the labors of his fellowmen, and to make them concur in attaining a useful purpose.

"To reach the best results by the easiest method" is a motto worth imprinting indelibly on the mind of every embryo engineer. The optimum compromise between many conflicting requirements is the goal of the engineer in his design of machines, structures, circuits, and processes.

The *growing dichotomy* between the academic concept of engineering, held by many engineering educators and guiding much educational planning, and the realities of engineering practice was well stated some years ago in *Electrical Engineering*.[6] The academic view

> . . . maintains that an engineer is one who applies the findings of physics and chemistry, solidified in various electrical, hydraulic, or mechanical components, in a way which may be represented by equations of considerable mathematical complexity, to apparatus or processes, so as to obtain a predetermined operating characteristic from the whole. All of his associates are technicians, clerks, fabricators, designers, draftsmen, or managers but, in any case, not engineers. According to this view, an engineer is one who makes continued and uniformly complex use of mathematical equations. . . . [In contrast, the industrial view] holds that the engineer is one who, by virtue of this knowledge of the discoveries of physics and chemistry, and the developments of mathematics, and the realities of economics, is enabled, after some years of experience, to see problems of product application, construction, production, or management with a broad and mature view so that he is capable of making well-considered and reliable estimates of the consequences of action. . . . From this standpoint, people working in the highly erudite and attenuated technical fields are seen as technicians.

Not all engineering educators, possibly only a minority, hold the "academic" viewpoint described. Furthermore, the two views were exaggerated for emphasis but they are essentially authentic and they epitomize the major problem of these times in engineering education, a problem of such magnitude and importance that it must be faced and solved in practice if the engineering schools are to survive in more than name as the source of professional engineers.

This "academic" view, followed to its logical conclusions, leads to a program of study which will prepare young men for work in the universities but not for professional practice in industry. Engineering will continue, in any event, to be a major profession, but its leading practitioners may follow another route in pre-

[6] Walter La Pierre, "An Immoderate View of Undergraduate Engineering Education," *Electrical Engineering*, April 1951.

paring themselves for professional practice.

Education for Design

My remarks might be misinterpreted if I do not at this point re-affirm my strong convictions that increased emphasis on mathematics and science in the engineering curriculum was overdue and will be found, in its long-range effects, to have been enormously beneficial through broadening the scope of the engineer's competence. The more an engineer knows about basic and applied science and about methods of analysis, the better off he will be—*provided* that his knowledge is tempered by judgment based on experience and by the ability to synthesize knowledge and experience *into design concepts*. It is not the introduction of more of these subjects which is disturbing, but rather, the reduction or elimination of another component of the conventional curriculum, exercise in conceptual design under criticism as a means of motivating students and of ordering their knowledge with a view to its application.

Engineering graduates engage in many types of work—technical and non-technical—with the percentage engaged in technical work decreasing progressively with years after graduation. In the technical area, one can identify many functions, including teaching, research, design, development, management, manufacturing, construction, sales, and others in which engineering graduates find employment and are successful. The question then arises as to whether or not all of these functions are to be regarded as "engineering" and more specifically, whether the engineering schools should *consciously* aim to prepare their graduates for one of these functions, and which one, for several, or for all of them. All of these functions offer satisfying, challenging, and fruitful employment and nothing derogatory is intended regarding any of them by a discussion of whether they are "engineering" or not.

Analysis of these many technical functions discloses, I believe, that only design and development are uniquely related to the engineering profession. In research and in teaching engineering science, one finds a growing percentage of basic and applied scientists. In manufacturing, construction, technical sales and others there are many individuals who were educated in other fields or who came up through the ranks. It is perhaps fruitless to argue whether or not these many other functions in which engineering graduates engage are really "engineering"; it is pertinent to emphasize however that *design* is the *central* and *characteristic activity* and that without this function, the engineering profession would lose its coherence and identity. More importantly, it is through engineering design that society receives the "pay-off" for scientific and technical activity. It is the responsibility of engineering schools and of the profession to see to it that this essential activity is creatively and efficiently performed.

Research and development have been so much associated in the public mind, as to obscure the fact that they are fundamentally different activities. Development which seeks to achieve a defined and, hopefully, a useful goal is essentially a sequence of design, test, and re-design; for the purpose of these notes it is treated as a phase of design.

The record of success achieved by the engineering profession in the United States must be ascribed in some measure, I believe, to the past program of engineering education. Perhaps the graduates succeeded in spite of their education. Perhaps they would have been more successful if their programs had included more of science and the humanities. Such a select group of students would have made their mark in any event in some field; exposed to technical subjects they succeeded amazingly well in engineering. I suspect, however, that in spite of its many deficiencies, the conventional engineering curriculum which prevailed through World War II was sound in basic principle and deserves a great deal of the credit for this record of professional service.

Engineering education expanded rapidly in this country during the last half of the nineteenth century in response to two social trends: first, the urgent need

for engineers in support of the industrialization and growth of the North and West and, second, the demand for an expansion of higher education to break the monopoly of the few then established universities. The pattern of engineering education was strongly influenced by these circumstances; relatively large numbers admitted directly from high school, four-year terminal program to limit student expense and to permit early practice, curricula oriented towards design competence in the chosen field, faculties made up predominantly of practitioners, little attention to graduate study, and other features we well know, were the result of these formative influences, during the period of its growth. Hindsight reveals weaknesses in these programs but they met the need of the times, graduating large numbers strongly motivated toward engineering practice. The process of selection after graduation sifted out the designers—around 25% of the group—and the remainder found satisfying employment in the other functions mentioned.

The point I wish to stress is that the program of engineering education in nearly all schools prior to World War II, and in a decreasing number of schools today, emphasized engineering design as the central theme. Attention to science and mathematics was inadequate—at least for today's practice—and liberal studies were given slight attention, but the graduates were carried to a point of competence such that, after a period of internship under professional guidance, they engaged effectively in the professional engineering function of design.

Developing a Viewpoint

Following World War II, the engineering schools undertook a revision of their programs in recognition of the tremendous expansion which had occurred in the basic and applied sciences and in the related techniques of analysis. Substantial changes *were due* in recognition of the rapid advances in some branches of technology and the obsolescence of others. More attention was needed to selecting those elements of academic preparation best suited to providing *the basis for a lifetime of engineering practice*. Rote learning of design techniques was discarded. The generalizations of science and mathematics applicable to a wide range of phenomena were given increased attention. Dull and repetitive laboratory and drafting courses were eliminated or reduced in scope. The humanities and social sciences were given a larger share of the curriculum. All these changes were in the right direction. They were overdue. They will vastly improve the competence of future engineers—*but in making these changes the engineering schools did not keep in mind—and, in my opinion, did not recognize clearly*—the primary reason for their past success, which was *the development of a viewpoint* and only secondarily the acquisition of knowledge and skills. This viewpoint is one of absorbing interest in identifying worthwhile design and development problems, in conceiving feasible solutions of these problems, and in realizing these solutions in practice—*and* pride in this *unique* competence. Knowledge and skill in analysis are valuable aids to engineering practice, but they are means to an end and not the end itself. An engineer becomes a "professional" not through vast knowledge of science and mathematics, but through knowledge *pertinent* to the field of his practice, judgment based on discerning experience, creative ability *and* a willingness to accept responsibility for decisions on the use of men, money and materials to achieve his ends.

Instilling this viewpoint in the engineering graduate must be reinstated as the central theme of engineering education and as the primary reason for the existence of engineering schools if these schools are to continue to play the dominant role in preparation for professional engineering practice. If the engineering schools persist in their present trend toward preparing their graduates to engage mainly in teaching and research, the leaders in engineering practice in the future are likely to be graduates in physics, chemistry, architecture, business administration and other fields. Students are not unaware of what is being said and done in engineering education and

they are drawing the logical conclusion that, if engineering is the mere application of mathematics and science, the best approach may be through science itself. If you doubt this conclusion, look at the facts about student choice in schools having a common first year in science and engineering, where the trend is strongly away from engineering and toward science.

The cause of this recent change in student interest lies in the engineering schools themselves more than in the glamour and publicity of science. They are not pursuing the old objective in a modern way but rather they have changed course entirely—perhaps it would more accurately describe the situation to say that they are adrift in the doldrums. Engineering and science are fundamentally different—and in some respects conflicting—activities which, nevertheless, have much in common in basic subject matter, and in educational preparation. However, these common elements have *obscured those fundamental differences* which should guide and control educational plans.

Engineering as an activity will continue, and grow in importance, so long as mankind survives on this earth. Men will design and build machines, circuits, structures and processes and combine them into systems and plants. It is of the utmost importance to our survival as a nation that this function be performed with increasing economy and creativeness. It is the duty and the opportunity of the engineering schools to prepare men for this work—and they should now re-examine their history, their objectives, their policies and their programs with this end in mind. It is my conviction that such a re-examination, objectively made, would lead to the reinstatement of design as the central and unifying theme. Only minor changes would be necessary in the *modernized courses and curricula*, but a major change in viewpoint would be required.

The term "design" has been used deliberately in these notes in spite of unfortunate connotations in the minds of some faculty members—implying detailed drafting, laborious calculations of structural or machine parts, safety factors as a substitute for analysis, and so on. As used here, *design* connotes the art of isolating and identifying worthwhile and *probably solvable* problems, of conceiving solutions of these problems in real components and systems, of analyzing these concepts in quantitative terms, of providing intelligible guides for manufacture or construction, and of comparing the predicted and achieved performance—and in practice, all within a predicted time and cost and usually with the objective of a profit, public or private. Creativeness in design ranges from the flash of genius, which we term invention, to minor modifications to improve performance or to match specific operating conditions. It is not a monopoly of engineers; ideas for new developments come from many sources. Genius is rare and unevenly distributed in time, place, and interest. What the engineering profession has done, in effect, is to accept the fact of the scarcity and uneven distribution of genius and to make up for it by educating and organizing average men to achieve small but numerous advances, distributed over a broad front. If society were content to duplicate exactly the existing machines, structures, circuits and processes, technicians could do the job, but the drive is always toward improvement and innovation, to substitute machines for men, to produce more per unit of effort, in short "to achieve the best results by the easiest method."

Invention is said to consist in the intuitive recombination of past experience. This statement is also true of engineering design, which must start from a concept, a mental image of something which does not yet exist which is pieced together from experience, direct or vicarious. Until a concept exists, analysis is impossible. It is the failure to recognize this fact which has, I believe, caused the growing dichotomy between engineering education and engineering practice. The usual situation is that the professor "designs" the problem—being careful to exclude all considerations not treated in his course—which the student analyzes. Many so-called design courses are taught as an exercise in analysis. Seldom is the stu-

dent assigned an economic-physical objective and then asked to conceive a component or a system to achieve this objective, and yet this approach is the essence of engineering practice. I believe that the future status and character of engineering schools in this country will be decided by the extent to which they recognize this difference in viewpoint and implement it effectively in their programs.

There is no one answer, and usually no absolutely best answer, to a problem in creative design which has been stated only in terms of the ultimate objective. Analysis can be applied only to specific situations and is therefore much easier than the synthesis of a design which may take on an infinity of aspects. It can be taught systematically and students can be appraised, at least to some degree quantitatively, on their mastery of the facts and the techniques studied. Design is difficult to teach and to appraise. Instructors should be knowledgeable and experienced, not so that they will know, and point out to the student the correct solution, but so that they can *collaborate* with the student through the suggestion of approaches to be tried, through knowledge of sources of data and theory, and through criticism of the results. When there is one answer, or when the instructor gives the impression that there is only one and he knows what it is, the course may be useful but it is not design. To the maximum extent possible some designs of each student should be brought to test, a major item of expense but not impossible if attention to this requirement is given in choosing the problems.

Creativity, probably, cannot be taught but it can be exercised, and through the opportunity to exercise it, it can be recognized. At the very least, it should not be inhibited, which is, I fear, the consequence of so much sharpening of "analytical tools" of design without assaying an attempt at design itself. In this respect, the engineers could learn much from the architects, who may be weak on analysis but who stress design early and late in their education. If the engineering schools do no more than recognize those who have a flair for creative design, encourage them to exercise their talent, and help them to find appropriate employment, they will have met a large share of their obligation. A few creative individuals can supply basic concepts requiring the efforts of a large group of scientists, engineers, managers, technicians, and skilled workmen to carry through to working equipment and systems; without these creative individuals, the remainder of the effort will yield only mediocrity. A question which engineering schools must face is whether their tightly knit and almost wholly analytical curricula are challenging and attractive to men of creative talent.

Regarding the design problems which students might attack, they are almost infinite in number and there are an unlimited number suitable for all levels of preparation and ingenuity. Instruments for measurement and control alone will provide enough design objectives for a portion of the design sequence in any field of engineering. The laboratory equipment and facilities for instruction and research in an active engineering school provide numerous design problems, many of which can be brought to test. Re-inventing something which exists, but which is probably not known to the student, is a fruitful exercise for beginners, and one can go on from there to unlimited variations in old and new machines, structures, circuits and processes. I visualize an expanding segment of the curriculum devoted to design, beginning possibly with one unit per term in the freshman year and increasing to as much as one-third of the year following the B.S. degree. In this sequence, the choice of technical objectives would be transferred gradually from the instructor to the students, who will complain about this responsibility but who must sometime undertake this key activity, the sooner the better. The concept that the teacher should know the answer and should lecture the student on how to analyze any problem posed is deeply engrained in the thinking of both students and faculty and will be difficult to change, but a change must be made if reasonable attention to design is to replace the present overemphasis on analysis.

Educational planning, especially the planning of programs for professional practice, must contemplate large groups but must do so in terms of the growth and development of individuals. To quote Sir Eric Ashby, "Universities must be firm in rejecting any implication that they are concerned with man-power. They are not. They are concerned with individual men." Society needs an increasing number of specialized professional groups and must somehow, through private or public channels, provide both the opportunities for preparation and also the inducements necessary to cause an adequate number of qualified individuals, acting freely, to elect each field. As their part in this process, the educational institutions should:

1. Offer programs which do *in fact* provide preparation basic to a lifetime of professional practice.

2. Impose admission requirements appropriate both to the difficulty of the academic program and also to the aptitudes and personal qualities essential to successful professional practice, to the end that there is a reasonable probability of graduation and of later practice.

3. Provide counseling based on intimate and timely knowledge of the requirements, the opportunities, and the rewards of each profession to the end that students may choose wisely in the light of their individual desires, qualifications, and circumstances.

4. Eliminate unnecessary and arbitrary restrictions both in admissions and in the program of study. The criterion of what is necessary should recognize the fact that a professional practitioner should also be an educated man.

These requirements may seem obvious and trite to some; others may object to them as falling, in part, outside the responsibility of the educational institutions. They are pertinent, I believe, to the ability of the institutions to meet their obligations to the students, to the professions, and to society. In engineering education, these requirements have not been met to an acceptable degree and, what is more to the point, there exists no comprehensive factual basis on which they could be applied.

The engineering profession, as practiced by engineering graduates, covers a tremendous sweep of functions and technologies and one can find within it selected examples of successful practice which would justify almost any preparation, including no collegiate studies whatever. No comprehensive study of the profession, comparable with that of medicine, law, and architecture, has been made and one cannot identify those features of the engineering curricula of the past which were either effective, useless, or harmful. The results of engineering education were, on the whole, good. Drastic changes, such as are now in progress, imply that we have sifted the good from the bad in past practice and are proceeding to improve and strengthen what was good. I doubt that we have the facts necessary for this judgment; I have the strong impression that the engineering schools are proceeding in the wrong direction, but this is an impression, also unsupported by adequate facts. Pertinent questions are: Is the trend in engineering education leading to curricula suitable for all the students admitted? Are the programs being developed suitable for only a small fraction of the present *graduates*? Are the programs realistic in terms of the requirements of *professional* practice in all of the technical functions in all fields of technology? Are individual schools attempting to serve too broad a range of technology and of technical functions? Are the academic requirements being raised above the realistic requirements for practice to such an extent as to deny to individuals the opportunity to prepare for branches of engineering in which they could practice successfully and to deny to society the services of these individuals? Finally, are the schools bent on preparing students for teaching and research in universities or for the practice of engineering? Answers to these questions are necessarily subjective and equivocal because the available, pertinent facts are fragmentary and conflicting. On the one hand, there is growing need for engineers knowledgeable in

basic science, and qualified to follow the advances of science, in order to apply this knowledge to new technological requirements. It is also true that the many mature areas of technology continue to serve society; the appropriate educational preparation in these areas differs little today from that of the past. Academic prestige sways administrative discussions in favor of the former but our industrial society depends on engineers practicing over the whole spectrum of technologies, from extreme novelty to full maturity; in terms of numbers of engineers required, the prosaic, mature areas of practice probably predominate.

Recommendations

The preceding considerations lead me to several specific proposals for consideration by those schools which aim to prepare students for modern professional engineering practice, as follows:

1. Reinstate design as the central, unifying theme in the engineering curricula; organize sequence in design which will recognize and exercise originality and creativity. Drop the "how to" courses in design.

2. Abandon the bachelor's degree as the accredited terminal degree. Retaining this degree, though unaccredited, is probably desirable.

3. Develop improved and integrated programs of study through the bachelor's degree plus one year as the accredited sequence. Adequate preparation for truly professional practice now requires 5 years. Planning 5 years as an integrated whole will considerably affect the distribution of subjects in the third, fourth, and fifth years.

4. Limit the professional content of the curriculum to the design sequence and devote the remainder of the time to basic and applied science, mathematics, and the humanities.

5. Emphasize laboratory work in all years, including graduate, and stress unprogrammed experiments of the student's choice and to his plan. If creative design consists in the recombination of experience, this experience should begin as early, and be as extensive, as possible.

6. Include in the laboratory program, or somewhere, extensive exposure to the methods of manufacture or construction by means of which engineering designs are brought to reality. The assumption that the knowledge can be acquired completely through experience after graduation is fallacious and American engineering practice is suffering through this lack. At least the student should be made aware of the effect of properties of materials and manufacturing methods on design and on the related costs.

Applying these suggestions would not require a change in the new and revised courses found in most of the engineering curricula today, but would require a major change in viewpoint and emphasis. My thesis is that the primary objective of the engineering schools should be to prepare the majority of their graduates for engineering practice and that the central and characteristic activity of engineers is design. Not all schools need give the same emphasis to design. Other objectives, notably research in the engineering sciences, must be effectively served but, in the aggregate, the engineering schools will harm this country's ability to sustain and increase productivity if they do not develop engineer-designers of superior ability.

MATERIALS ENGINEERING AT ARIZONA

The Department of Mining and Metallurgical Engineering of the University of Arizona's College of Mines will offer the Master of Science degree in materials engineering beginning in September, 1961.

Engineering Graphics—A Predictor for Academic Performance in Engineering

STEVE M. SLABY

Associate Professor of Graphics
Princeton University

ARTHUR L. BIGELOW

Assistant Professor of Graphics
Princeton University

I

For many years it has been the opinion of those in the Department of Graphics at Princeton University that there might be a correlation between a student's work in graphics and his later academic performance. In communicating with others in the field, we learned that this opinion was not ours alone and that in a few instances some research had already been undertaken to determine to what degree the correlation might exist. For the most part, studies of the subject were quite limited and were undertaken only for the information of the schools interested. The results of these studies were not generally published, and indeed notes on the results are not readily available. The authors of this study felt justified, therefore, in exploring the matter further in the belief that our findings might possibly shed some light on the value of graphics as a predictor of a student's potential in the field of engineering.

We chose three courses followed in the freshman year, courses fundamental to the formation of an engineer: mathematics, physics, engineering graphics. This last course embraces two areas—engineering drawing and descriptive geometry. It was our intention to correlate a student's grades obtained in these courses to the grades obtained later in his chosen field of engineering, as represented by the junior-senior departmental average of the grades in the chosen field.

At first it was thought that an indication could be obtained by taking a few random classes, applying a correlation coefficient equation, and then interpreting the results. It was later reasoned, however, that if the study was to be at all significant, at least a full decade should be covered and all the classes in that decade considered. Hence the ten years 1950–1959 inclusive were chosen as being of the most immediate interest. It was felt that if there should be any particular trends or if any predictive potential existed, a continuity of ten classes would certainly reveal them.

II

Our first step was to apply the standard correlation coefficient equation to three classes, those of 1950, 1953, 1956, to determine if this approach would show anything significant. Using the equation

$$r = \frac{\Sigma (x - \bar{x})(y - \bar{y})}{\sqrt{\Sigma (x - \bar{x})^2 \Sigma (y - \bar{y})^2}}$$

where r = correlation coefficient,
x = grade in course,
$\bar{x}$ = arithmetical mean of all grades in course,
y = junior-senior average in departmental course,
$\bar{y}$ = arithmetical mean of the junior-senior grades,

correlation figures were determined ranging from .65 to .74, a difference of only .09 among the several courses tested, with first one then another taking the high position.

Though all entering students considered had of course studied mathematics

and physics in secondary school, only a third, or less, had had prior experience in engineering graphics. Even so, the correlation coefficients for engineering drawing and descriptive geometry were as significant as the figures for mathematics and physics. However, in our opinion, this method failed to offer any really significant comparison between freshman performance and later junior-senior departmental performance in the chosen field of engineering, and since it indicated that no one course was outstanding as a predictor we therefore decided to investigate the problem from another approach. A direct "group comparison" was made of the performance of the classes in mathematics, physics, engineering drawing, and descriptive geometry, to the junior-senior departmental performances for the entire decade, 1950–1959.

In this study, only those students were included who entered with their class, continued as members of the class, and graduated with the class.

III

The grading system in Princeton is based on numbers, called "groups," 1 to 7, with pluses and minuses indicating high or low standing within the groups.

A 1+ denotes a percentage of 95 to 100; a 1, 92 to 94; a 1−, from 89 to 91, and so on down to 5−, where this lowest passing grade denotes a percentage from 60 to 63. A 6, a failing grade, denotes a standing from 50 to 59, with a 7 for anything lower.

This part of the work consisted in bringing together all grades in each course, in every year for the entire decade, in their respective groups, 1+, 1, 1−, etc., charting them and comparing them to similar charts compiled from the junior-senior departmental averages or grades.

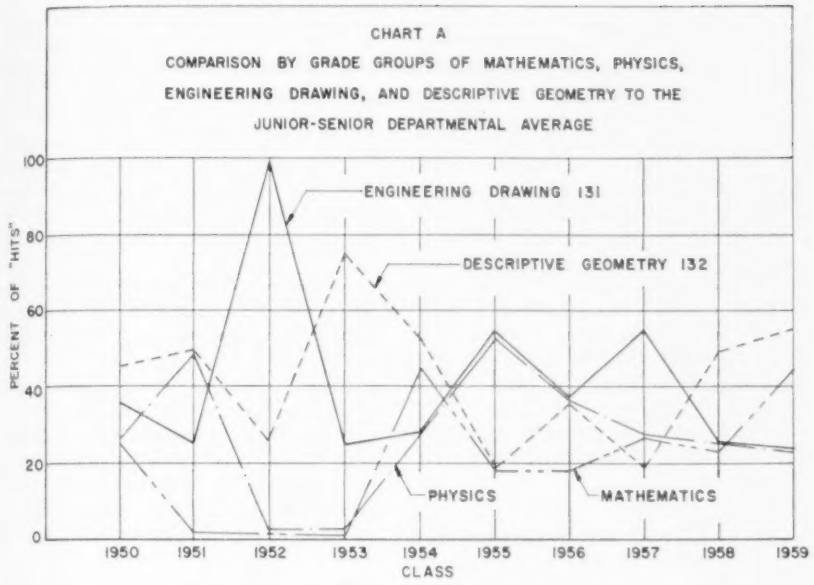
It was remarked that there was little comparison between the graphs for the junior-senior departmental averages and the graphs for courses in physics and mathematics. The latter courses show considerable differences in form, and in only rare cases do the grades represented approach normal bell-curve distribution. On the contrary, the junior-senior departmental average curves agree almost entirely. Again, differing from mathematics and physics, the courses in engineering drawing and descriptive geometry show definite consistency in grade distribution.

Grades in the graphics courses are based on a strict standard, each grade corresponding to a percentage value and each item in the courses (problems, tests, drawings, quizzes) being evaluated on the basis of 100%. This means that each part of an exercise is weighted according to difficulty, the weighting based on past experience. Grades thus obtained are recorded for each student. The average term grade for each student is calculated by further weighting of each major part of the course (for example, class problems 50%, tests 30%, quizzes 20%). From this it will be seen that an attempt has been made to get as objective a grade as possible for each student; "curve fitting" is not practiced in any engineering graphics course taught at Princeton. The grade earned by the student, according to this system of evaluation, is the grade recorded.

In the comparison of performance by grade groups, all grades were tallied according to group, for all courses and for all classes, and their totals tabulated. The junior-senior departmental averages were tallied in like manner and the tallies for the courses then compared to them.

If the tally for grades in a course was the same as the tally for the junior-senior departmental average, this constituted a "hit," and the tallies in the other courses were not considered. If, however, there was a tie between two course tallies, both tallies were included in the comparison to the junior-senior departmental average tally, thus constituting a "hit" for each course. If none of the tallies was equal to the junior-senior departmental average tally, then that tally which was the closest was taken and considered a hit.

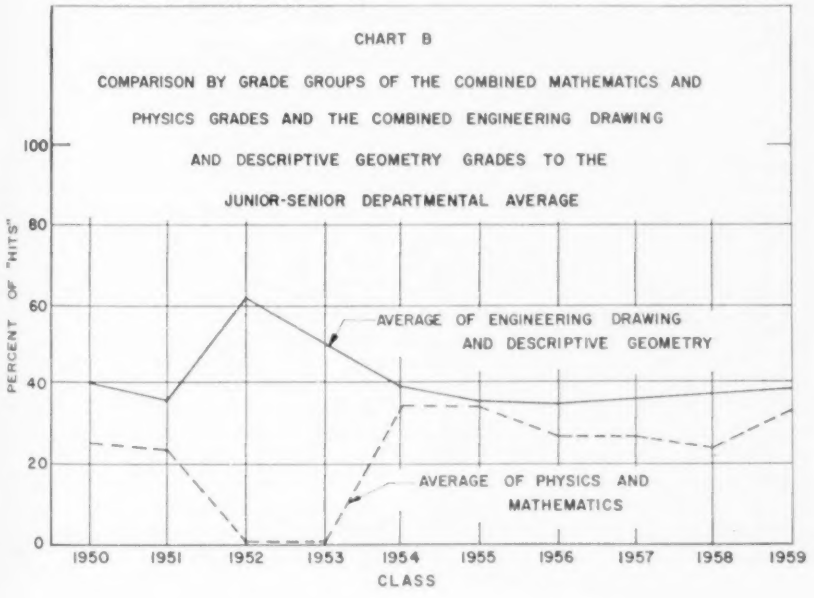
The number of hits were then totaled for each course, then compared to the number of hits possible, and a percentage taken. (A total of 11 hits was possible for each course, 1+ through 4. Nothing



lower than group 4 is accepted as a junior-senior departmental average.)

It can be seen from Chart A that, during the decade, both graphics courses tend to be better indicators of later departmental performance than either mathematics or physics.

Then to compare the graphics courses as a whole to mathematics and physics courses as a whole, we averaged together



the percentage of hits for engineering drawing and descriptive geometry, and the percentage of hits for mathematics and physics, and plotted Chart B. One line thus expressed the graphics courses, and the other the combined mathematics and physics courses.

According to Chart B, graphics courses consistently indicate a closer relationship to junior-senior departmental performance. It can be seen that the mathematics and physics courses, from 1950 to 1954, have a much lower predictive value than the graphics courses. For the years 1954 and 1955 there is a close correspondence between all courses; from 1956 on, mathematics and physics drop below the courses in engineering graphics as an indicator of later scholastic performance.

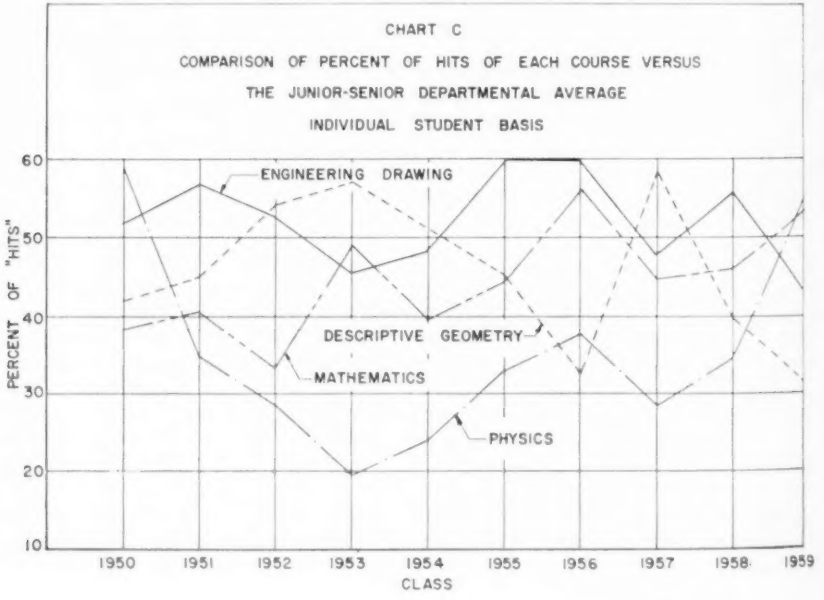
IV

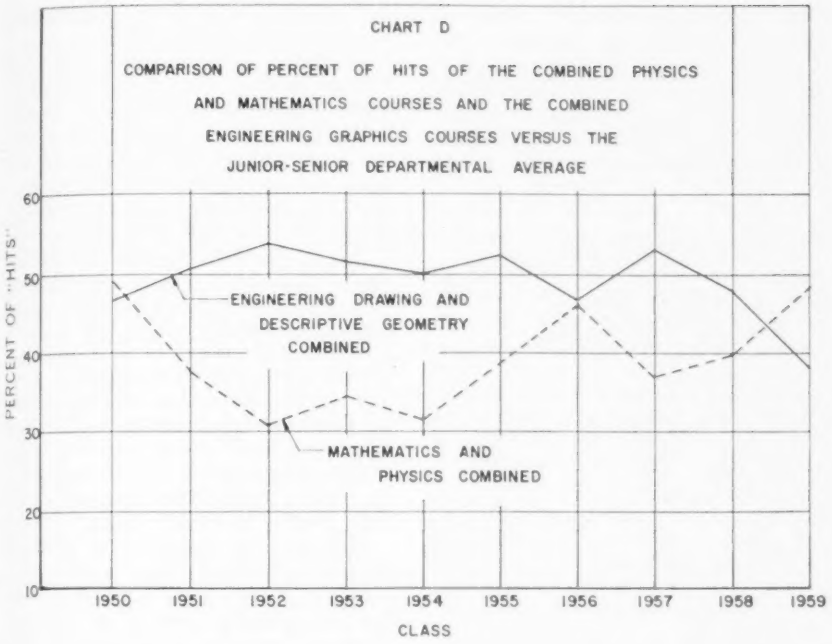
Indicative though it is by group, it was felt that a student-by-student comparison, with his grades in the four freshman subjects compared directly to his junior-senior departmental average, would be of the greatest service in determining the predictive value of any one course.

Accordingly, each student's junior-senior departmental average was listed, from 1+ to 4. When the student's grade in any of the four courses considered either corresponded to the junior-senior departmental average or came within a half-group of it, it was recorded as a hit.

In each class, percentages were figured between the total number of students in the class as against the number of students whose departmental averages corresponded directly to their grades in the subjects considered. Each time direct correspondence was achieved, constituting a hit, it was recorded for percentaging with the junior-senior departmental average.

Chart C shows that in 1950 physics recorded the largest number of hits: 59.5%. Engineering drawing came next with 52%, descriptive geometry came third with 42.3%, and mathematics fourth with 38.4%. For the years 1951 and 1952, both engineering drawing and descriptive geometry recorded a higher percentage of hits than either mathematics or physics. In 1953, descriptive geometry stood out as the highest; mathematics and drawing, practically together, came next, with physics a low fourth. From 1950 to 1958, physics registered a lower percentage of hits than any other





course. From 1957 to 1959, physics indicated a steady climb.

Mathematics consistently records a better percentage of hits than physics, but except for the years 1950 and 1959, engineering graphics courses consistently register a larger—much larger—percentage of hits than either mathematics or physics courses.

We then combined mathematics and physics, on the one hand, and the two graphics courses, on the other, and charted the two combinations.

Chart D shows the comparison of the percentage of hits of the combined engineering drawing and descriptive geometry courses, and the combined mathematics and physics courses, vs. the junior-senior departmental averages.

The chart shows that during the years 1950–1958 the engineering graphics courses combined record a higher percentage of hits than the mathematics and physics courses combined.

The results of this part of the study, as indicated by Charts C and D, show that, in general, engineering graphics courses again exhibit a greater capacity as predictors of later scholastic performance in engineering than does either mathematics or physics.

V

The results of the individual comparisons established above were then broken down into the several departments which comprise the School of Engineering: Aeronautical, Basic, Chemical, Civil, Electrical, Geological, and Mechanical. We reasoned that it would be interesting to discover how the predictive value of the graphics courses applied to these various branches of study—even though at the time that the mathematics, physics, and graphics courses were followed, the field of engineering a student was later to enter had not as yet been chosen.

Class by class, the number of hits in a subject by aeronautical engineers, basic engineers, etc. were counted, compared to the number of students figuring in the class, and a percentage taken. Finally, the averaged percentages of hits for the decade were established for the courses in engineering graphics vs. the courses in mathematics and physics.

In each engineering department, courses in engineering graphics registered the greatest percentage of hits, again demonstrating that the graphics courses exhibit a greater capacity as predictors of later scholastic performance than either mathematics or physics.

VI

From the "direct comparison" approach, both by group and by individual student, it appears that, as with mathematics and physics, the work in engineering graphics is fundamental to engineering education. According to the results of this study, the close and consistent coordination of performance in graphics with that in junior-senior departmental courses gives engineering graphics a basic importance which sometimes has not been apparent outside this field.

It would seem that a definite pattern has been established here. With but two exceptions, graphics proves to be a consistent predictor. It is interesting to note that the exceptions to the pattern occur at the beginning and end of the decade, under what may be termed abnormal conditions. The class of 1950 was composed largely of veterans, with backgrounds quite different from those of average freshmen. The class of 1959 was unusual in the abnormally large percentage of the entering students who, for one reason or another, left engineering before graduation.

From our investigation into the possible predictive value of mathematics, physics, and the engineering graphics courses, for later academic performance in the chosen field of engineering, we can establish the following results:

1. There is a definite and close correspondence between a student's performance in freshman engineering graphics courses and in his later junior-senior departmental courses, both by group comparison and individual comparison.

2. The correspondence of performance in engineering graphics courses *vs.* performance in the junior-senior departmental courses is significantly better generally than the correspondence of freshman performance in either mathematics or physics *vs.* later junior-senior departmental courses.

3. The results of this study show that for the span of an entire decade engineering graphics courses prove consistently to be better predictors of later academic achievement than mathematics, and a far better predictor than physics.

4. As a predictor, engineering graphics operates for students of all levels and in all departments. All through the classes, from the exceptional student down to the average, there is a high percentage of correlation.

The conviction on the part of those who teach graphics and others who are acquanted with it, that there exists some vital connection between work in graphics and a student's later academic record, seems to be justified. Furthermore, graphics is seen to be the best predictor.

Why does it occupy this position? Seeking a reason, can it not be that there is some facility or aptitude needed for work in graphics which is also intrinsic in the student's later engineering reasoning? Is not the student's proficiency—or the flair he develops—in dealing with problems of plane and space also an ingredient in the solution of later engineering problems? One of the central disciplines of an engineer's thinking is mathematics, and the science of mathematics originates from geometry and the concept of space, both basic in graphics. A student's ability to visualize and to express the geometry of a problem would seem to underlie his ability to visualize more complicated problems, understand them, and organize his solutions. This being so, there is every reason to develop in the prospective engineer those qualities of perception and judgment which graphic expression embraces.

Graphics is part of the thinking of an engineer, though he may sometimes be unconscious of it. From its close relationship to mathematics, it is a significant part of the science of engineering and takes its place along with mathematics and physics as indispensable for the proper education of engineers.

Until a few years ago a test in spatial relations was among those given by serv-

ices in educational testing to prospective engineering matriculants. For some reason, the test was dropped. In the light of the continued—and even augmented—numbers of transfers out of our college engineering courses, and in the light of the results of this study, it would seem logical to consider reinstating the spatial relations test as an indicator of aptitude for engineering studies.

Within the past few years, owing to the alarming number of withdrawals, efforts have been made to determine why so many students drop out of engineering. "Inaptitude" is, of course, often indicated, as is also "lack of motivation." Whichever it be, the conclusion is unavoidable that these students have been "wrongly chosen."

Just how can motivation be measured? Educators, and educational testers, are not yet in agreement on this—if they ever can be. But it is important that in the near future tests be devised and administered by which, it is hoped, the presence or absence of motivation can reasonably be determined. The ideal, admittedly remote, is to admit to our schools of engineering only those students who, having shown promise through scholastic achievement at the pre-college level, will also stick by the course until they graduate. And if "disposition to" or "motivation" is difficult to determine, so is ability. There is always the encouraging fact that the student's capacity for learning is quite measurable by his aptitude in the sciences, and by the record he has made in his secondary studies.

There remains, however, something else besides motivation, scientific aptitude, and success in school, something else that must be taken into account before the student is admitted to engineering school—if we are to reduce the growing number of withdrawals from engineering. Those who withdraw are all too often students who are selected from the top-most ranks in school, and who show the greatest promise for a successful career in engineering. But they are found to be lacking that other element which an engineer must have, that further competence—the ability to understand a situation, to grasp the given facts, to select the materials to consider, and to realize the place that these factors occupy and how they fit together. The concept of space, the ability to *think* space, is a principal element contributing to this competence. And one sure indication of ability in this area is the test in spatial relations.

We do not maintain that every aspirant scoring high in such a test is a potential engineer, or that every student failing this test cannot become an engineer. But we are convinced that the ability to function in a space context is an important factor in judging potential engineering material. For it is this capability that will express itself later in the engineer's career, in his ability to conceive, to design, to *invent*. And a proper test in spatial relations would help to show us that ability which an engineer must have, and often a scientist does not have, that makes the difference between a successful engineering student and one who leaves engineering after the first, second, or third semester. Such a test would thus help to remedy a situation which results in a diminishing number of engineers, a situation which at this time the country can ill afford.

In conclusion, we feel that the results of this study underline the importance of graphics as fundamental to engineering. There is no question about the value of mathematics and physics in an engineering program of study; there is likewise little room for argument about the inherent value of engineering graphics as part of this same program of study. It seems evident that the ability to "think" space is a necessary condition if we are to define engineering correctly. By thinking space in mathematical terms, and by thinking space in geometrical or graphical terms, the engineer links the symbolic with the real. And this, in the final analysis, is just why he is an engineer.

Note: A detailed report on this subject has been published by the Department of Graphics at Princeton University. A copy of the report may be had upon request.

The Production and Use of Motion Pictures for Engineering Instruction

EDWARD JAMES RISING

Assistant Professor of Mechanical Engineering, University of Massachusetts, Amherst

Summary

To evaluate the usefulness of "minimum cost" motion picture films as instructional tools for teaching a computation laboratory course in engineering, three controlled experiments were run over a three-week study unit in which all the lectures of the treatment sections were given by minimum cost films. The findings were interpreted to indicate that there was no difference between the performance on criterion tests of matched treatment and control sections. This conclusion was reached on the basis of accepting the null difference hypothesis; the greatest weakness in the investigation was that the available sample size was rather small for this statistical technique. Two criterion tests were given, one immediately following the study unit, measuring the effect of learning, one two months later, measuring the retention. The minimum estimate of the reliability of any criterion test was .69.

Introduction

If the educational process in multiple-section courses is thought of as a man-machine system, typically the machine portion is rudimentary (chalk and blackboard) and the man portion is frequently tedious and repetitive. If the machine role can be expanded, the repetition and tedium can be reduced in the man role. Motion pictures provide a method of doing this and many other things. A completely filmed course of lectures will provide the advantages of broadening the influence of the more talented teachers, of easing the shortages of trained teachers, of reducing the per-student instructional cost, and creating a basis for teacher training within professional areas.

This investigation, covering a study unit which takes three weeks to complete in the course Engineering Problems as taught at the State University of Iowa, is a pilot study of the efficacy of using minimum cost motion picture films to carry the major instructional burden throughout a whole course. The course in which the experimentation was performed is required of all freshman students and is given two semester hours' credit. It meets twice a week during a sixteen-week semester for three hours each meeting as a computation laboratory. The material covered in this course is the use of logarithms and the slide rule to perform computation processes that are basic to engineering and the physical sciences. These techniques are applied to problems of conversion of units from one system to another, exponential equations of various types, and the solution of triangles and other problems of a similar nature.

The psychological reasons for choosing this course for experimentation were that the students taking the course have a wide range of ability levels because it is given to freshman students, and the sample size for the statistical populations was more generous than otherwise because it is a required course, and, finally, the course is of a mathematical nature and consequently representative of a type of course common in the engi-

This is a portion of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Industrial and Management Engineering in the Graduate College of the State University of Iowa, August 1959.

neering curriculum. The practical reasons for selecting this course were that it is a multiple section course, the content is stable; it is an expensive course in terms of teacher and student time; and consequently any advantage we obtain, educational or financial, will produce more total benefit.

The method of producing film for this investigation was suggested by the work of Greenhill and Kepler. Their concept was adapted to fit the needs of higher education. The films of this study were produced by the trained camera crews using the extensive facilities and multi-camera, synchronous-sound techniques of the State University of Iowa film production unit. The presentations that were filmed were essentially classroom lectures reorganized for the medium and rehearsed for smooth presentation.

Statistical Outline

The technique most often employed for the statistical design of methods experiments is to formulate a straw man in the form of a null hypothesis, e.g., "There is no difference between the treatments as measured by a criterion test." The "desirable" outcome of the experiment is to reject the null difference hypothesis and conclude that the treatments must be unequal, and proceed to detail the inequality. In back of this technique is the notion that a proposed (new) method is of little interest if it is not possible to reject the null difference hypothesis, i.e., if the new method is not demonstrably superior to the old method in current use.

The logic of statistical inference supports this approach, desirable to reject, non-reject, abandon, because of the nature of the two types of error to which every statistical test is subjected, i.e., Type I, rejecting a hypothesis when it is true, and Type II, accepting a hypothesis when it is false. If an experimental treatment is abandoned when the null difference hypothesis cannot be rejected, the practical consequence of a Type II (acceptance) error has been eliminated. Only taking action on the basis of rejected hypotheses eliminates any practical risk from an acceptance (Type II) error. Type I (rejection) error offers no problem because its risk is set in advance as the decision rule.

This investigation is unlike most methods experiments in that it is more vulnerable to Type II errors because a "desirable" outcome is acceptance of the null hypothesis. It is argued that administrative advantages, including decreased costs, make it desirable to change to the new film teaching method if it can be done without loss of quality. Of the three possible outcomes of a comparison between the old and the new methods, (a) the old method is demonstratably better than the new method, (b) the two methods are statistically indistinguishable, (c) the new method is demonstratably better than the old method, it then follows that either of the latter two conclusions is "desirable" from the point of view of the new method.

Experimental Method

Six films were produced to cover completely the content material of the three-week instructional unit on logarithms which is the first instructional unit in the course. Data were collected during both semesters of the 1958–59 school year; the student enrollment was the random sample of a population defined as the students, past, present, and future, who take the course.

The engineering ability of the students was obtained, for purposes of the experiment, from the Pre-Engineering Ability Test (Form ZPA) which was administered the first day classes met so that the measure of engineering aptitude dated at the start of the experiment. The treatment and control groups were matched by counting-off method (one for me, one for you, etc. starting from the top of the list of students arranged by engineering aptitude), and the ability levels within the treatments were constituted by dividing the matched groups into the upper, middle, and lower third based on engineering aptitude. The criterion measure for the experiments was a unit examination, given immediately following the study unit, and a portion of the final examination used to measure retention. Estimates of the reliabilities of these tests

TABLE I

DESCRIPTION OF THE EXAMINATIONS USED AS CRITERION MEASURES AT THE END OF THE STUDY UNIT AND AS FINAL EXAMINATIONS FOR EXPERIMENTS I, II, AND III

Characteristic	Ideals	Experiment I		Experiments II and III	
		Unit Test	Final	Unit Test	Final
Discriminations					
High (.40 and Up)	more than 25%	34%	50%	2.5%	14%
Moderate (.20 to .39)	more than 25%	40%	45%	37.5%	36%
Low (.01 to .19)	less than 15%	14%	5%	57.5%	41%
Zero or Negative	less than 5%	12%	0%	2.5%	9%
Score Statistics					
Mean		28.79	15.28	29.13	16.71
	(indicated)[a]	(25.78)	(13.75)	(25.22)	(13.75)
Standard Deviation		5.13	3.76	5.23	2.99
	(indicated)[b]	(5.08)	(2.75)	(4.92)	(2.75)
Reliability	more than, .70	.784	.798	.803	.690
Probable Error	no standard	1.60	1.14	1.57	1.12

[a] Midpoint of range between highest possible and expected chance score.
[b] One-sixth of range between highest possible and expected chance score.

vary between .69 and .80. The parameters of these tests are described in Table I.

Experiment I, during the fall semester, was an attempt to find out whether the films could provide a presentation as useful to the students as similar lectures given live to a matched control group by an experienced teacher; there was also an attempt to determine whether any improvement could be gained by a second showing of the films. The treatment groups in this experiment were designated I and II. The Treatment I group viewed the filmed lectures; the Treatment II group viewed the filmed lectures twice to test the effect of repeated showing; both of these treatments were compared to a matched control group.

Experiment II, during the spring semester, was to compare the results obtained from a treatment group conducted by a carefully supervised undergraduate teaching assistant, using the films and duplicated lecture notes, to the results obtained from the control group conducted by an experienced teacher presenting similar lectures live.

The control treatment in both these experiments consisted of live lectures given at the same time as the film treatments by the same person that appeared on the film. Choosing the same person who appeared on the films to make the live lectures for the control group was an attempt to hold down the variability due to different teachers. In this way, the test comes nearer to being a test of the usefulness of the films compared to live presentations.

Experiment III, also during the spring semester, was an attempt to determine whether the films and notes could be used in a class conducted by an experienced teacher (called the treatment group) to produce the same effect as another experienced senior staff member using his own methods of teaching (called the control group). This is the only experiment in which the control group was not conducted by the teacher appearing on the films, and, therefore, helps to "ground" the experiment. The former experiments may show differences exist, but this experiment indicates that the level at which we are making these comparisons is reasonably high.

It seemed desirable to make several types of comparisons with the data: first, to compare the average performance of the experimental and control groups; sec-

ond, if a difference is shown to exist in average performance, to determine whether the difference is general throughout the ability range of the students or selective in a particular ability range; third, if no difference exists between the average scores, to examine the data to see whether this may be caused by one ability level scoring disproportionately higher on one treatment and another ability level scoring disproportionately higher in other treatments so that the average remains the same.

Discussion

The results of Experiment I, given in Tables II and III, may be summarized as follows: It appears that (a) a generally experienced instructor never having taught the course before can achieve the same average results using minimum cost films as can an experienced instructor, teaching in person, who has taught the course many times; (b) there is no apparent benefit from showing the films a second time; (c) the results are similar for the unit examination, which measures the effect of learning, and the final examination, which measures retention.

The same "average" results can, of course, be achieved many ways; for example, the high-ability students of one treatment may score disproportionately higher than the high-ability students of other treatments which might be balanced by the low-ability students of the latter treatments scoring higher than the low students of the former treatment. This would result in a selectivity between the various treatments and the ability levels which appears in the analysis as interaction. No interaction was found in the unit examination data, and it is argued that the interaction observed in final examination data is not an "in fact characteristic" of the parent population.

The results of the tests made with the data from the final examinations for the

TABLE II

VALUES OF THE MEAN SQUARE RATIOS FOR "TREAMENTS," "LEVELS," AND "INTERACTION" (T × L) FOR EXPERIMENTS I, II, AND III

	Mean Square Ratios					
	d. f.	Treatments / Within	d. f.	Levels / Within	d. f.	T × L / Within
Experiment I unit exam	2 / 87	2.20	2 / 87	17.19*	4 / 87	0.72
final exam	2 / 82	1.03	2 / 82	13.80*	4 / 82	7.42*
Experiment II unit exam	1 / 33	.00	2 / 33	14.66*	2 / 33	.06
final exam	1 / 30	.46	2 / 30	.42	2 / 30	1.03
Experiment III unit exam	1 / 18	1.11	2 / 18	8.38*	2 / 18	.98
final exam	1 / 13	.84	2 / 13	1.74	2 / 13	5.56*

* Greater than the corresponding value of "F" at 5% probability.

TABLE III

THE MEAN VALUE OF CRITERION MEASURE FOR THE DIFFERENT TREATMENT AND LEVELS FOR THE THREE EXPERIMENTS

		Unit Exam Data				Final Exam Data			
		Control	Treatment I	Treatment II	Level Average	Control	Treatment I	Treatment II	Level Average
Experiment I	High	33.79	30.93	31.80	32.27	19.00	16.79	17.40	17.82
	Medium	28.36	28.64	26.00	28.12	14.14	16.79	9.60	14.58
	Low	27.21	24.12	25.20	25.61	14.00	13.00	16.00	13.88
	Treatment Average	29.79	27.90	27.67		15.71	15.52	14.33	
Experiment II	High	32.71	33.14		32.93	17.57	18.43		18.00
	Medium	30.86	30.43		30.64	18.00	16.43		17.21
	Low	26.29	26.14		26.21	18.00	17.29		17.64
	Treatment Average	29.95	29.90			17.86	17.38		
Experiment III	High	30.50	29.25		29.88	18.75	15.75		17.25
	Medium	29.25	31.50		30.38	13.25	18.25		15.75
	Low	21.75	25.50		23.62	17.00	11.25		14.12
	Treatment Average	27.17	28.75			16.33	15.08		

Sample Size Note: Experiment I began with 14 cases in each cell of the Treatment I and control groups and 5 cases per cell in the Treatment II group. Experiment II started with 7 cases per cell and Experiment III with 4 cases per cell in all groups. Because several students dropped the course before completion some data was "lost" to the analysis.

presence of interaction can be accounted for because of the large amount of data "lost" from the experiment due to students withdrawing from the course. The pattern of this "lost" data shows many more students dropping from the lower ability levels. Since the data suggest that even within the lowest ability category it is the poorer students that are dropping, this lowest ability category has a systematic upward bias (i.e., elimination of the lowest individuals from a category raises the average score of the group). This bias should account for the interaction effect that was detected.

The numerical results of Experiment II were much the same as Experiment I. The interpretation of the results of Experiment II, given in Tables II and III, may be summarized as follows: (a) A carefully supervised undergraduate teaching assistant, using films and duplicated lecture notes, can produce the same effect as an experienced teacher giving the same lecture in person; (b) this result is similar for the unit examination, which measures the effect of learning, and the final examination, which measures retention.

The final examination data of this experiment do not present a clear picture because approximately 15% of the data has been "lost."

Two impressions were obtained during the course of this experiment. First, little effort, in addition to carefully previewing the film with the teaching assistant, is necessary to properly instruct the teaching assistant to conduct any particular class. Second, the teaching assistant appeared competent to introduce and summarize film presentations. These impressions suggest that it would be possible for one experienced teacher to utilize and control a number of teaching assistants. The fact that the duplicated lecture notes, used during this experiment, were accepted and used by the students in the same manner as personally taken notes indicates that the dif-

ficulties which students usually have taking notes from film can be satisfactorily overcome with material that can be prepared in advance.

The results of Experiment III, given in Tables II and III, may be summarized as follows: (a) Two experienced teachers both having taught the course many times before, one using the films and duplicated notes and the other his own teaching methods, can achieve the same results; (b) these results are similar for the unit examination, which measures the effect of learning, and the final examination, which measures retention.

In this experiment there are only four cases in each ability level category for each treatment (cell) to start with, and there is a very high percentage of data "lost" before the final examination. Therefore, the results of these calculations should not be considered conclusive. It is interesting to note that the results, for what they are worth, are compatible with Experiments I and II in that there is no significant difference between treatments, and similar to Experiment I in that there is observed interaction between treatments and levels. In the Experiment III final examination data, however, there is no significant difference between levels, which is probably due to the systematic upward bias on the lower ability level cells caused by the poorer students dropping the course after the unit examination and before the final examination.

Costs

The expendable supplies required for the production of the six films used in this study cost an average of $260.53 per film. A careful estimate of the total cost of labor to produce each film, including camera men, film editor, and processing technicians but not including the teacher-actor, was made at $100.00 per film. Subsequent to this experiment, fifteen additional films on slide rule computations were produced. Expendable supplies for these films averaged $290.00 per film and an estimate of $100.00 per film for technical labor, as before, seems appropriate for these later films.

During the academic year, teaching assistants, under the immediate supervision of a senior staff member who will incidentally be conducting a teacher developing program with these assistants, will use these films in combination with duplicated lecture notes to present all the course material to the students. It is estimated that $1750.00 will be saved during one academic year. Thus, the cost of producing the films can be quickly amortized even if the computation does not include any estimate for income that may be obtained from the sale of these films.

Conclusions

Two major conclusions seem to emerge from the evidence that has been discussed: First, students can learn both conceptual and factual material from this type of film, and they apparently learn as well as from the same lecture presented live under similar circumstances; and, second, this type of film offers a promise of being (a) economically feasible on a self-amortizing basis for repetitive, multiple section courses, (b) useful for extending the influence of superior teachers, and (c) helpful for teacher training.

Bibliography

1. Rising, E. J., "The Use of Minimum Cost Motion Pictures for Engineering Instruction," Unpublished Dissertation, State University of Iowa, Iowa City, Iowa, 1959.
2. Greenhill, L. P., Kepler, L. F., "A Study of the Feasibility of Local Production of Minimum Cost Sound Motion Pictures," *SPECDEVCEN* Project 20-E-4, 1955.
3. Kumata, Kidaya, *An Inventory of Instructional Television Research*, Educational Television and Radio Center, Ann Arbor, Michigan, 1956.
4. Dale, E., F. W. Dunn, C. F. Hoban, Jr., E. Schneider, *Motion Pictures in Education*, American Council on Education Committee on Motion Pictures in Education, H. W. Wilson, 1937.
5. Hoban, C. F., Jr., E. B. Van Ormer, "Instructional Film Research," *Technical Report No. SDC 269-7-19*, 1951.
6. Lindquist, E. F., *Design and Analysis of Experiments in Psychology and Education*, Houghton Mifflin Company, 1953.

Biomechanics Research

HERBERT R. LISSNER

Head, Department of Engineering Mechanics, Wayne State University, Detroit, Michigan

A Biomechanics Research Center has just recently been established at Wayne State University following twenty years of research activity made possible by the cooperation of the Colleges of Engineering and Medicine. In order to indicate the nature of the work to be performed under the auspices of this Center, some of the projects which have been undertaken by the group at Wayne in the past will be described.

From the mechanics standpoint the human body is a beautiful machine, far superior, we believe, to any man-made machine or structure. Consider any single organ, the heart for example, that operates continuously for years. The amazing thing is not that failures occur, but that so many of them operate so long without failure. Or consider the application and control of forces accompanying the motions of a dancer, where a mass of over 100 pounds weight is moved through ever changing patterns. When attempting to consider the individual muscle force application and timing to produce this motion, one is constrained to say with the psalmist, "Truly man is fearfully and wonderfully made."

All of our investigations have been performed by teams consisting of various people from the College of Medicine faculty and members of the staff of the Engineering Mechanics Department. Each man has made his contribution to the research, not as a consultant, but as an active participant in his specialized area of knowledge. In addition to the scientific results obtained, each man has enjoyed and been stimulated by his contacts with people in areas of specialization vastly different from his own.

Much of the research undertaken has been for the purpose of obtaining basic knowledge only. In this category are the tests performed to determine the strength characteristics of human bone. Thousands of tests have been conducted on samples of bone taken from various individual bones to determine the tensile and compressive strength and modulus of elasticity. These factors are affected by the age of the individual and the bone from which the sample was obtained and whether the bone is a fresh sample or has been embalmed, but average values for compact bone are 12,000 psi ultimate tensile stress and 18,000 psi ultimate compressive stress with the modulus of elasticity being about 2.25×10^6 psi. Spongy bone as found on the inside of long bones has entirely different characteristics than compact bone and might be compared to foam plastic. Our investigations in the tensile and compressive strength and modulus of elasticity of spongy bone are continuing at the present time.

When we started our tests of bone, we used dry samples and obtained perfectly straight stress-strain diagrams to rupture. When some wet samples were tested accidentally, we found that the stress-strain relationship gave a large curve following an initial straight portion. Since this indicated a much greater energy absorbing capacity, it is fortunate that the bones in our body are kept moist.

Another of our studies involved the determination of the deformation pattern produced by an impact to the human skull. To make this study, we planned to use stresscoat on dry human skulls, but the validity of the results obtained from dry skulls was questioned. We therefore

Presented at the June, 1960, Annual Meeting of ASEE, at Purdue University.

began our tests with living anaesthetized dogs and monkeys, reflecting the scalp and applying stresscoat to the living skull. The crack pattern in the stresscoat was obtained after delivering a hammer blow to the skull and then the animal was sacrificed. Several days after death, after the old lacquer coating had been removed, a new coat of stresscoat was applied and the identical impact repeated. Finally, the skull was removed and dried and the same test repeated again. A comparison of the resultant crack patterns indicated that while the extent of the deformation differed, the patterns obtained in all three tests were similar. With this justification, we proceeded to make tests on dry skulls.

By coating the skull inside and out, we were able to obtain an indication of the deformation behavior of the skull due to a blow. Some regions bend inward while others bent out simultaneously, and it was the outbending that was generally responsible for the production of fractures. In order to determine where the first linear fracture would occur due to a blow in any area of the head, we selected 100 skulls at random and divided each one into twelve areas. Again using stresscoat we struck each of the skulls in each previously defined area, making a total of 1,200 tests (not counting those which were unsuccessful). As a result of this investigation, we were able to produce an atlas which gave the probable fracture site due to a blow in any region of the head. The uniformity of fracture location is quite surprising considering the variation in size and shape of heads. For example, we found that a blow to the side of the head well behind the ear would produce a fracture in the temporal region on the same side in 85 per cent of the cases. This atlas has been of use to radiologists in examining x-rays for fracture when the site of the blow was known. An additional use has been to infer the site of the blow from the position of a demonstrated fracture for medical legal purposes.

We have made use of the previously obtained data in another series of tests in which we attempted to obtain the energy required to produce a simple linear skull fracture and the time of absorption of this energy. For this test, we used 60 intact cadaver heads and cut away the scalp to expose the bone in the region where the fracture was to be expected. We cemented an SR-4 strain gage in this area and dropped the head on a heavy steel block. The heads varied in weight from 7 to 14 pounds and we assumed all the energy was absorbed by the head. When the fracture occurred, the strain gage circuit was opened and it was determined that the energy was absorbed in about 0.001 second. The energy required to produce a simple linear fracture varied from 300 to 1,000 inch pounds with an average value being about 500 inch pounds. We also found that very little additional energy beyond that required for a simple linear fracture would produce a very severe multiple fracture and depression. Incidentally, the fractures we obtained in these tests were in good agreement with predictions obtained from the previous stresscoat tests of dry skulls.

In order to determine difference in fractures obtained with high velocity impact, we dropped steel balls of different weights down an elevator shaft, striking the skull at the bottom. Up to a velocity of 45 feet per second a single linear fracture was obtained, but at 90 feet per second a clean round puncture was produced. Hammer blows to intact heads at intermediate velocities produced depressions under the head of the hammer with some stellate linear fractures surrounding the depression.

When we first started our tests, we had no difficulty securing sufficient experimental material, but since the social security program guarantees a burial to all of its participants, our supply has dwindled appreciably due to the vigilance of the morticians. And in Michigan you can't will your body for medical research—it belongs to your heirs—so it must be done with their approval.

We have conducted static and dynamic tests of complete long bones in compression, bending and torsion to study their mode of failure and determine the stress distribution in the bone with the aid of stresscoat. Bone is

weaker in tension than in shear so a torsional load produces a spiral fracture as is frequently seen in skiing accidents. We have run fatigue tests on bone samples and on complete bones taken from the foot. Fatigue fractures actually occur clinically—primarily in the Army where they are called march fractures. The normal individual applies about 10 million cycles of load to the bones of his feet and legs in a year's time.

We made a series of static and dynamic tests on the pelvis and spine for the Air Force to determine the stresses imposed by ejection seat operation. We tested individual vertebra of the spine and individual spinal disks in compression as well as testing the complete pelvis and lumbar spine. In tests in which we dropped the lumbar spine and pelvis, we used stresscoat to determine the resultant deformation of the pelvis. Since the load distribution was not correct when the pelvis and spine alone were dropped, we removed the legs and exposed the pelvis of a series of cadavers. We then dropped the entire cadaver onto a steel block, striking the bottom of the pelvis and obtaining the strain pattern with the aid of stresscoat.

In none of the preceding tests were we able to produce a ruptured disk, so we set up a compressive fatigue test of the lumbar spine. We used a spring 4 inches in diameter coiled from steel rod $\frac{5}{8}$ inch in diameter in series with the spine and, in one test, after 500,000 cycles of load, the spring broke, but x-rays showed no damage to the spine or disks. Repeated bending of the spine after removal of the muscles and tendons gave some evidence of the possibility of disk rupture but, of course, in the living the muscles and tendons take the tensile load in bending. Further testing in this area is necessary to obtain significant results.

In order to obtain the response of the skeleton to acceleration, an accelerator was built and installed in a vacant elevator shaft 10 stories high. A carriage is driven along a track and is brought to rest by brakes which grip the rails. The machine can accelerate an entire cadaver at 50 g for one tenth second. This acceleration is obtained by air pressure acting on an eight foot long piston connected to the carriage. At the end of the eight foot stroke, the carriage is travelling 120 miles per hour. The shape, magnitude and duration of the acceleration pulse can be varied and at present we are measuring the effect of varying the jerk or rate of acceleration on the strain produced in the spinal vertebrae which have strain gages bonded to them. In addition to measuring strains in various bones in the body due to various positions and restraints, we also measure accelerations at various points. And, we have obtained the effect on the skeleton of various kinds of cushions and pads on the seat under the cadaver.

A recent test was initiated when an automobile manufacturer wanted to obtain a material to simulate the skin over the knee to determine the lacerative effect of instrument panel knobs. We suggested the use of fresh pigskin and then the question arose regarding how closely its mechanical characteristics approached those of human skin. So we made tests of both in tension, compression and shear, obtaining load deformation curves, and found very good correlation for these properties.

One of our projects required a method for measuring the forces exerted by the muscles in the calf of the leg. These muscles are connected to the Achilles tendon which is attached to the calcaneous bone at the back of the heel. We made a tendon dynamometer which, when clamped to the tendon, registers the force exerted on it by means of a strain gage cemented to an element of the clamp. This dynamometer can be worn with no discomfort and muscle forces can be measured directly when wearing high or low heeled shoes, walking, running, jumping, etc. We believe that the design of the dynamometer can be modified to permit its application to many other tendons in the body for direct measurement of muscle forces.

Our graduate students who have an interest in biomechanics take a course in anatomy and in physiology from a member of our research team, in addition to their regular mechanics courses. They

also choose a problem in biomechanics for their thesis. One such thesis was concerned with brain tumor localization. It involved the design and construction of a gamma ray collimator and its use by the student to localize brain tumors of patients in the hospital. Another thesis topic required that the blood flow rate in the carotid artery in the neck be determined without cutting into the neck or introducing any mechanical device into the artery to obtain the measurement. The student solved the problem by injecting radioactive iodine into a vein in the arm and noting the passage of the radioactive front through the artery by means of two gamma ray collimators placed two inches apart along the artery, having both beams focused on the same scintillation crystal. The diameter of the vessel is determined from an x-ray taken when a radio-opaque liquid is passed through it. From tests made on dogs, with the blood flow actually collected and measured, the greatest error in the tests performed was four per cent.

Our research on the mechanism of concussion covered a long period of time. We started our tests using anaesthetized dogs, delivering hammer blows to the exposed skull and measuring the acceleration and the intracranial pressure produced with strain gage pickups. The degree of concussion produced was determined from measurements of respiration and blood pressure. Since the hammer blows frequently produced depressed fractures and since no pattern of relationship between the measured variables and concussive effects could be determined, we decided to modify the test procedure. Since the blow produced internal pressure within the brain both by accelerating the head and by deforming the skull, we applied air pressure pulses directly to the brain. These were controlled in magnitude and time and we found that large pressures (60 psi) lasting a short time (0.001 second) produced the same concussive effect as low pressures (15 psi) lasting a long time (0.2 second). We also found however that there was no relation between impulse (pressure times time) and the concussion produced. In examining the skull we note that it is a closed vessel with an opening at the foramen magnum through which the spinal chord passes. If a pressure is produced in the skull, a pressure gradient will exist in the brain stem region above the foramen magnum which will tend to extrude the brain into the spinal canal, setting up shear stresses in this region. The magnitude of the shear stress is proportional not only to the pressure in the cranial cavity but also to its time duration. The brain stem region contains the mechanism which regulates breathing, blood pressure and pulse rate and depression of this area produces unconsciousness. After making further tests we removed the dogs' brains for examination by a pathologist. His examination showed damaged cells (and ruptured blood vessels with severe concussions) in the brain stem area above the foramen magnum and in no other region in the brain. We then made a plastic model of a one inch wide section of the skull containing the foramen magnum opening and filled it with milling yellow, an aniline dye which is doubly refracting when subjected to shear stress. By photographing the patterns obtained when the model was struck, using a speed of 500 frames per second, we demonstrated the presence of high shear stresses in the brain stem region.

In conducting tests of head impact against instrument panels for an automobile manufacturer, we measured the pressure within the cranial cavity of the cadaver and compared the pressure magnitudes and time duration with that known to produce concussion. For these tests the brain was removed and replaced by gelatin of the same specific gravity to insure that no air spaces existed within the head. Other impact tests have been made against laminated and tempered safety glass to determine the injury potential of each. Tests are presently being conducted at velocities up to 35 miles per hour to determine whether or not concussion would result from such impacts.

Another test presently being conducted for a safety helmet manufacturer is to determine whether the skull should be permitted to deform or prevented from

deforming when it receives a blow. It might be safer to permit the skull to deform somewhat and thus absorb some of the energy of the blow rather than prevent its deformation and thus increase its acceleration.

Other investigations under way or about to begin involve stress distributions in the mandible and other bones of the face due to normal forces on the teeth and external impacts; effect of severe blows to the chest and resultant blood surges in the venous system; and studies of whiplash injury of the neck as frequently occurs in rear-end automobile collisions.

One area in which we have made no investigations but believe that much can be learned to benefit the engineer is the study of biological material with a view of improving engineering design. A study of the long bones would have told us that the best design for members subjected to bending and compression is a thin strong shell filled with a light-weight honeycomb material. And a study of the skull would have revealed that the best energy absorbing panel would consist of two hard plates separated by a soft energy absorbing material. A recent study of the skin of the porpoise has indicated a design, which when applied to the surface of a submarine, should permit its speed to be doubled with no increase in energy requirements. We are confident that further studies of this sort will lead to information which will prove to be of great value in engineering design.

Continued studies of the tolerance of the human body and its parts to acceleration and impact forces are of utmost importance to establish design parameters which can be used by engineers in producing designs which will provide maximum safety to occupants of automobiles, airplanes and rockets.

RUTGERS ADDS NEW FACILITIES

President Mason W. Gross has announced approval of design plans for the biggest single building project in the history of Rutgers University, a $5,450,000 engineering center composed of four connected buildings.

Dr. Gross said that construction of the engineering center is scheduled to begin next summer on the science campus at University Heights in nearby Piscataway Township.

Dr. Gross pointed out that the present engineering facilities on the men's colleges campus will have to be maintained by the College of Engineering to serve the increasing needs of those departments not scheduled to move to University Heights.

The new center, which will contain 177,000 square feet of floor space, will enable the college to double its present enrollment, which now stands at about 700 students. The center is designed for future expansion to accommodate the entire college and the anticipated 1970 enrollment of about 2,500 students.

Professional Grade Surveying Education for Civil Engineers

MAX O. LAIRD

Assistant Superintendent-Field Engineering, Western Electric Company, Defense Projects Division, New York, N. Y.

Abstract

Surveying is intrinsically a complex mathematical science with roots in astronomy, geophysics and other sciences, but nurtured for centuries by the civil engineering profession, of which it is an inseparable part. The civil engineer cannot abandon surveying or be ignorant of appropriate field survey or office interpretation procedures without degradation of the quality and economy of his designs. Collaborating professionals look to the civil engineer to furnish professional-grade advice on geodetic and geophysical problems.

General mediocrity in engineering education and the near elimination and superficiality of university surveying courses are both the effect and cause of inadequate expenditures of time and money and the failure to challenge and attract faculty and student talent to surveying. Most of the current content of surveying courses is high school and technician grade *training* which should be segregated from the university *education* of engineers and replaced by exacting courses in rigorous theory. It is time to abandon our life of luxurious mediocrity, turn off the television and get busy with mature home work.

Recommendations include a 6-year engineering course comprising 3 years of mathematics and sciences, 1 year of English, humanities and engineering management, and 2 years of applied art of engineering. The civil engineering course should require 13 semester hours of rigorous surveying theory with 8 semester hours of appreciation application of surveying in summer camp. The principal civil engineering schools should offer 25 semester hours of graduate credit surveying electives, on a collaborative basis with other Universities and with extension facilities available to employed graduate engineers.

The following are formal notes prepared in advance of a panel discussion of "The Place of Geodesy in Required Civil Engineering Courses," by R. C. Rautenstraus, M. O. Laird, L. G. Simmons, C. I. Aslakson and K. S. Curtis, American Society For Engineering Education, Purdue University, June 24, 1960. These notes are restricted to general aspects of the subject and to applications of surveying and mapping to engineering projects.

Status of Surveying for Engineering Projects

Control, boundary, planimetric, topographic and route surveys of some appropriate character are necessary to provide basic information for the design of engineering projects involving sites or routes. The effects of omissions, inaccuracies, blunders, or inappropriate surveys are design difficulties, incompatible design and subsequent construction difficulties involving lost time, extra compensation for false work and high bids on subsequent jobs. The total expense for surveys and maps is generally in the range 0.1 to 1.0% of the total cost of an engineering project and dependent engineering expense is in the order of about ten times the survey and map expense.

Considering that surveys of some character are required for design, and the relative orders of risks and costs involved, it seems only elementary good manage-

Presented at the 1960 Annual Meeting of ASEE.

ment to require appropriate accurate surveys by competent engineers. Paradoxically, engineers, architects and scientists commonly delegate both the planning and performance of surveying work to inadequately trained technicians employing obsolete or defective instruments and procedures.

Good work *is* specified and obtained by some offices and produced by self- or job-educated engineers or high-grade technicians with superior analytical ability, thoroughness and objective determination. That this usually results from the employment of an adequately educated survey engineer is the basis for our hope in discussing this subject with the critical objectivity which the currently unfavorable climate for surveying warrants. Education is effective. It is costly but not nearly so costly as the lack of it. The inadequate education of engineers is particularly hazardous considering present world conditions.

The Decline of Professional Competence in Surveying

There is a substantial literature discussing various aspects of the shortage of truly professional engineers. The situation is particularly acute in the field of surveying and mapping where great strength and agility, a "gun" and a "chain," a rumpled, weatherbeaten appearance, and bad economic judgment are commonly assessed as the requirements for practice of this intrinsically complex applied mathematical science.—This is no joke.—The very thorough and able study of the status of surveying and mapping by the Barry, Whitmore, Quinn Committee for ASCE disclosed initial doubts in the minds of substantial numbers of engineers that surveying was engineering or that engineering was professional work and that facilities for the education of truly professional survey engineers are practically non-existent in the United States.

Surveying education in American universities has been reduced to the extent that some civil engineering graduates have no significant knowledge of the subject and few attain more than an appreciation level. Concomitantly, the apprentice system has deteriorated, under economic and social changes, to the point of substantial ineffectiveness. The result is a plethora of badly trained technicians and a paucity of professional grade survey engineers, effectively self educated or developed in the few organizations where low-grade surveying and mapping work is not accepted. The many scholarly manuals written by our panelist Lansing Simmons, and by others in the Coast Survey, have contributed to the self education of a cadre of geodetic engineers essential to many non-government engineering offices and likely to become more essential in this age of space vehicles. We are not without talent in this country but we are coasting on the heritage of grandfathers and incurring great risk to our future by compromising surveying education to its near extinction. It has been estimated that our annual accession by all means is only 25 to 50 geodetic engineers.

The *Proceedings of the Canadian Institute of Surveying*, particularly the January 1960 issue reporting the October Colloquium on Survey Education, reflect a similar situation but more effective apprentice technician training in Canada. The situation in the rest of the Americas is far less than satisfactory but has improved as a result of operations under Point 4 and IAGS.

In Europe the survey engineer is educated, operates and is recognized as a professional. The principal technical universities offer a 4-year engineer course, a 5-year diploma engineer course and a 6-year doctorate course in "geodesy," including the geophysical sciences, land use and planning, and the economic and administrative elements related to surveying and mapping. In European practice the several surveying categories are elaborately defined and controlled, with the work being allocated to those educated, trained and licensed for the particular category. Abstracts and occasional translations indicate competence and great activity in surveying and in surveying education behind the Iron Curtain.

Some few European geodetic engineers are doing good work in the United States

and Canada, in spite of handicaps of differences in language and operational philosophy. To look to Europe for the education of survey engineers to supplement the badly trained lot of technicians we call "surveyors" is untenable in this highly competitive world. It is time to abandon our life of luxurious mediocrity, turn off the television and get busy with mature home work.

Degenerative Influences and Their Reversal

Examination of how we were reduced to this situation is profitable only to the extent that it indicates a way out.

The Dead Hand of Civil Engineering

At the Ottawa Colloquium, Dean Thompson of University College, London, made many strong and some mutually inconsistent statements, including the charge that, "Surveying education has been grossly retarded by the dead hand of civil engineering. The major advances in surveying have been made by people who had nothing to do with civil engineering." The charge that the civil engineering profession has abandoned surveying has been made by others in recent years.

These statements serve only to mislead us by confusing small elements of truth with large adulterations of sophistry. Surveying had its roots in astronomy, mathematics, the geophysical and other sciences but has been nutured for centuries as an inseparable branch of the discipline of civil engineering. The civil engineer's designs are based on survey data and effected in accord with construction surveys. The civil engineer cannot abandon surveying or be ignorant of appropriate field survey or office interpretation procedures without degradation of the quality and economy of his designs. That civil engineers have not abandoned surveying is indicated by the fact that 40% of authors of papers in the recent consecutive meetings of ACSM/ASP in Washington had basic civil engineering educations. This is an appropriate level of contribution considering that many papers related to instrumentation and to specialized uses of the surveying and mapping products.

It is true that ASCE, ACSM, ASP, AGU, EJC, ECPD and other professional societies with some relation to surveying have been noting the decline of surveying education without taking effective steps to reverse the trend. The recent work of the Barry, Whitmore, Quinn Committee for ASCE has been highly effective in documenting the present situation and this committee is now working on the additional task of recommending specific plans for improvements of surveying education and the practice of surveying. The Canadian Institute of Surveying is active in consolidating the good work of the 1959 Colloquium and seems likely to improve materially the situation in Canada. ACSM is beginning to act on the job of estimating requirements for surveyors and for surveying education. The professional societies are a little late in awakening but the appropriateness of the words "alarming" and "crises" which they now use seem likely to be more effective than the reassuring language in the preambles of their several constitutions.

Mediocrity in an Age of Great Technical Competition

During the past several years Admiral Rickover has had a lot to say about progressive education and creeping mediocrity in American science and engineering. His warnings are confirmed by the charts of economists showing trends in output and productivity in the United States and in the world which is fast overtaking us. It seems clear that a professional grade engineering education cannot be acquired in less than 6 years and we will need to provide the plant and staff and to divert time and money from distracting luxuries to education. The alternative is to be overtaken since the pouring of vast sums of money into projects will not compensate for the lack of adequately educated personnel to engineer and conduct them.

Education of Engineers in the Science and the Art of Engineering

There has been a lot of debate on the question of science versus engineering as

an art, primarily as the result of the tyranny of words in information releases on atomic and missile projects. Most of the scientists involved in these projects are in fact practicing engineering, with various degrees of competence, and the engineer without a sound grounding in mathematics and science is badly prepared for the practice of engineering in this age. The days of both the universal scientist and the so-called practical engineer are gone and will not return. Lead time between research and application has virtually disappeared. Modern projects and component design elements commonly involve combinations of the several engineering disciplines and require thorough education of the engineer in mathematics and basic sciences. For example, all engineers are now commonly involved to some degree with electronic components and circuitry. Similarly, man in space is involved with some first-order problems of guidance and geodesy. Modern practice requires not only greater appreciation level knowledge of the several engineering disciplines but greater specialist knowledge and greater awareness to seek and accept the advice and collaboration of specialists in particular categories. It is reasonable for other engineers to assume that the civil engineer will have a workable knowledge of the several geophysical sciences—a field he has neglected for many years. Similarly, it is reasonable for the civil engineer to expect the electronic engineer, the physicist and other specialists to contribute to the advancement of surveying and photogrammetric instruments and procedures. No apology need be made for these contributions which reflect only good practice in the use of the common body of scientific knowledge and the collaboration of specialists.

Segregation of Engineering Education from Technician Training

Expansion of the field of required basic knowledge for engineers and the practical limitation of time make it infeasible to *train* the engineer in the associated skills of the technician. There is a very great need for improvement and expansion of the facilities for education and training of increasing numbers of technician grade assistants. This seems properly the work of institutes, which might be associated with universities, but which should be segregated from the professional grade *education* of engineers.

There are evidences of the need for improving the engineer's background in the humanities, English, and the elements of business management, engineering economy and motivation techniques. At least 1 year of these liberal arts and engineering management elements, 3 years of basic mathematics and science and 2 years of the art aspects of the elected engineering discipline would seem appropriate. The organization of these broad criteria into systematic courses of study requires the specialized skills of administrative educators.

Superficiality in Surveying Education

The current superficiality of our surveying courses reflects both the effect and in large measure the reason for the failure of our university surveying departments to meet the ever-present competition for student and faculty talent and for time and money in the university programs. Substantially all of the nonconformal plane, route and elementary astronomic surveying currently offered in our universities is high school and trades school level material—the educational failure of simple arithmetic and repetitious technician grade training to challenge students or faculty. Some surveying instructors have become so fascinated with the manipulation of instruments that they have forgotten how to use their heads. This is not in accord with the instrinsic nature of surveying which should be made a most exacting scientific subject for both faculty and students.

Surveying cannot be taught to students without a workable knowledge of the calculus. Part of the current difficulty has its origin in admission defects which need to be corrected by a sound transition program in our high schools. It seems reasonable to contemplate a near-future requirement for engineering students to enter the university with a fairly usable knowledge of physics, geometry, algebra, trigonometry and elements of

the calculus and to acquire workable knowledge of physics and calculus during the first one or two university semesters.

Surveying cannot be taught by part-time instructors with inadequate surveying education and experience or from superficial texts slanted toward the handbook engineer or the technician. The surveying educator needs to be a competent geodetic engineer. A woeful lack of professional-grade faculty talent is documented in the frank replies of university surveying department heads in response to a recent search for geodetic engineers for summer employment on arctic defense projects.

Compensating Influences and Improvement of the Climate for Surveying

It is recognized that this objective critique of the currently unfavorable climate for surveying education omits mention of the good work being done under difficult conditions and emphasizes the weaknesses noted in the literature and in actual practice. About a quarter of my time is spent in preparing plans, instructional material and specifications for control mapping and construction surveys but more time than is reasonable is spent in investigating discrepancies and patching weaknesses in the work by engineers, including university faculty members, and by technicians. That my observations are not unique or my comments unduly critical is confirmed by conversations with other management engineers and with university educators and by general agreement of the thoughts set forth in the independently prepared drafts of the collaborators on this panel.

The situation is bad but not hopeless. We have the residuum of talent and facilities required to reverse the currently unfavorable trend. To effect thorough exacting surveying education requires only the abandonment of an apologetic whipped attitude, the aggressive promotion of a motivating array of facts, and specialized skill in drafting a reoriented professional grade program of required and elective courses. There is need for the practicing engineer and the several professional societies to exercise their duties to contribute to the advancement of the art by assisting in the array of facts and requirements. The following particular views on the subject will need to be adjusted for best fit with the many other observations necessary to the proper definition of the problem. Collaborative help is obtainable and we are indebted to some few professors and practicing engineers who are seeking it with foresight and determination.

General Recommendations for Transitional Survey Education

There are current indications that general acceptance of the need for something like a 6-year truly professional education for civil engineers and the staff and facilities for effecting it cannot be obtained for some years. The prospect of stimulating appreciation for and entrance into the field of surveying by sufficient numbers of professional grade educators and practicising engineers seems even more remote. Accordingly, it seems necessary to contemplate both a long range objective program and a transitional program involving the practical expediencies of:

1. Establishing some effective means for the education and training of technicians and translating to this program the greater part of the time-consuming elements of the field measurements and routine office work. Most of the current content of elementary plane surveying, field astronomy and route survey courses should be transferred to the technician training programs. Other parts of route surveying are intrinsically elementary geometric design which should be translated to the technician program and to the related specific design courses.

2. Cramming a limited theoretical study of the broad fields of surveying and mapping into the current 4- or 5-year course, with the objective of obtaining appreciation level by most engineers and by all civil engineers. A sufficient number of the more apt civil engineers should be inspired and better prepared for continuing study of the more complex theoretical and art phases of surveying in

the graduate school or with limited assistance during sub-professional practice. Upgrading of the faculty to professional geodetic or photogrammetric engineer level should be accomplished in the transition phase.

There is great merit in a "Theory of Engineering Measurements" course for all engineers provided calculus is a prerequisite and the course is not reduced to a stalking horse for elementary surveying. Great losses result from inappropriate conclusions and actions derived from faulty analyses of empirical and statistical data by engineers or from the failure of engineers to recognize defects in analyses made by others.

3. The firm offering of graduate courses in surveying and mapping in some few adequately staffed large civil engineering schools, preferably on a collaborative basis with other universities and with extension facilities available to employed graduate engineers.

Many of the advanced courses listed in university catalogs are now mere fiction, owing to lack of staff and students, and some "advanced" courses are strictly "rim-fire" calibre. The granting of the degrees Master of Science in Geodetic Engineering, Master of Science in Photogrammetric Engineering and Master of Science in Land Surveying and Planning are recommended on completion of a 6-year professional-grade course.

Tentative Outline of Surveying Courses for Civil Engineers

Required for All Engineers

1. Theory of Engineering Measurements —2nd Sem—3 SH
   Elements of engineering statistics, agreement and validity, accuracy and precision, errors and blunders, sampling theory, rational inference, distribution, curve fitting, probable errors, rejection, combination and adjustment of independent and conditioned observations by the method of least squares. With appreciation level lectures on statistical methods and on the scope and character of measurements in the several fields of engineering.

Required for Civil Engineers—(Optional for Other Engineers)

2. Theory of Surveying—3rd Sem—5 SH
   Elements of geophysics, geodesy, geodetic and conformal plane coordinate surveying theory. Spheroids, geoids, conformal and non-conformal projections. Geodetic and conformal plane coordinate computations. Geodetic astronomy. Horizontal control by triangulation, traverse and trilateration. Vertical control by spirit, trigonometric, barometric and other leveling. Tidal datum planes. Orthometric and dynamic corrections. Elements of aerial surveying, ground control, photogrammetry and photo interpretation. Optical tooling and special surveying applications. Reduction, least square adjustment and computation theory in greater detail, but with emphasis on theory and computations on only a sample basis. Proof checks and the detection of blunders (transcription errors, wrong star, etc.). The atmosphere-visibility and refraction. An exacting theoretical course with no field or laboratory periods.
3. Surveying Instruments and Methods—4th Sem—5 SH
   Optical, electrical and mechanical constructions, theory of operation, precision, accuracy, systematic errors and procedure for minimizing their effects. Leveling, angle, direction, distance, aerial survey, photogrammetric, and optical tooling instruments of all types. Accuracy, speed and economy of various methods. Reconnaissance planning and strength of figure for control. Distance-measuring instrumentation, procedures and accuracies. Topographic methods, requirements, scales and their relation to land forms and uses for the map or information for electronic computations. Rationalization of correct procedures in relation to the critical study of the effects of systematic and accidental errors. Lecture and recitation with expedited demonstration of proper procedures and a very min-

imum of training in the actual use of instruments.

4. Surveying Camp—Summer between 4th & 5th Sem—8 SH
   Practical field instruction and performance of control, topographic, hydrographic, astronomic, preliminary and construction engineering and route surveys, computations, sample plotting, ground control for aerial surveys and simple photogrammetry and photo interpretation. Development of judgment in planning and application of the theory developed in preceding courses should be emphasized. Time should not be wasted in repetitious observations, computations and drafting or in attempts to develop technician grade excellence in manipulative skills.

Elective for Civil Engineers (Graduate Course Credits)

5. Theory of Least Squares—6th Sem—5 SH
   A rigorous study of the adjustment of observations.
6. Geodetic Surveying—7th Sem—5 SH
   A rigorous study of horizontal and vertical control, astronomy, conformal coordinate systems and a brief history of geodesy .
7. Geodesy and Geophysical Surveys—8th Sem—3 SH
8. Topographic, Hydrographic and Aerial Surveying—9th Sem—5 SH
   (Includes photogrammetric and all appropriate procedures)
9. Aerial Photo Interpretation and Special Applications of Photogrammetric Procedures and Data—10th Sem—3 SH
10. Law of Boundaries and Cadastral Surveys—7th Sem—5 SH
    (This should be taught by an experienced specialist with both PE and AL licenses.)
11. Land Use, Subdivision, Industrial & Municipal Planning—8th Sem—5 SH
12. Special Applications of Surveying—As Appropriate
    This might include optical tooling, control and guidance for space vehicles, etc., which are appropriate to the age and the field of specialization of the university. Offered as required and generally on a symposium basis.

TRIBUS NEW DEAN AT DARTMOUTH

Professor Myron Tribus of the University of California at Los Angeles has been named Dean of the Thayer School of Engineering at Dartmouth College.

His appointment, effective for the next academic year, was announced by Dartmouth President John Sloan Dickey.

Professor Tribus succeeds William P. Kimball who asked last spring to be relieved of his duties as dean so he could devote full time to developing a new concept in civil engineering education that he calls "environmental engineering."

Growth in Undergraduate Hydraulic Engineering

JOHN C. GUILLOU

Research Associate Professor of Hydraulic Engineering, University of Illinois, Urbana

Two major changes in the teaching of undergraduate hydraulic engineering have occurred within the past twenty years. The first of these was the movement from empirical hydraulics to the more justifiable and rational fluid mechanics. The second large change, and one in which we are now involved, is the introduction at most institutions of a separate course in hydrology. Both of these changes were necessary for the development of a logical pattern of hydraulic engineering instruction. The purpose of this paper is to attempt to place some of the thoughts attendant to these changes in proper perspective, to outline a recently developed program in undergraduate hydraulic engineering, and to indicate what appears to be the probable future course of undergraduate hydraulic engineering. It would be presumptuous of me to infer that this paper brings together a great deal of material compiled by questionnaire. It does not. It does present some of the thinking and conclusions of the writer based on numerous discussions and experiences at three major universities during the past fifteen years. It also reflects the results of several studies made at the University of Illinois in conjunction with the recently completed revision of the entire undergraduate program in civil engineering.

Fair evaluation of any technical curriculum can only be completed against the backdrop of the very sizable number of credit hours that are devoted to nontechnical work. We are all facing up to serious problems of this nature in the social-humanistic area. Within the last 10 to 15 years virtually all accredited institutions have materially increased the number of hours devoted to such required subjects. Furthermore, many of us are requiring satisfaction of higher entrance requirements in mathematics and physical science, and are using the hours freed by this for further extension of the two areas at the college level.

The net result of the additional requirements is the compressing of the technical material, which is the backbone of civil engineering, into a relatively small portion of the student program. Because of this the pressure for complete elimination of time for specialty work, i.e. sanitary, hydraulic, highways, etc., is very strong. For example, in the field of hydraulic engineering at the University of Illinois, a normal undergraduate student who completes his program in four years is permitted only three 3-hour courses in his elected speciality of hydraulic engineering. One of these 3-hour courses is required, so in truth out of 144 hours of work only 6 hours, or about 4 per cent, of his time may be elected by the student in his chosen field of technical specialization.

The compressing of the technical program has required that engineering instructors exercise great care in allocating time for student study in their own specialized areas. Our experience is that this is both a burden and a blessing. It is a burden because none of us have the time to pursue topics to the extent which we believe is desirable. Conversely, however, it has proved to be a blessing in that areas utilizing hydraulic engineering background information have been quite willing to give up this instructional work to allow expansion of their own technical material.

A paper presented at the 68th Annual Meeting of the American Society for Engineering Education, Lafayette, Indiana, June 21, 1960.

The question of compatibility of specialization with providing a broad background in civil engineering is a large and complicated one. It appears that some of the attributes of specialization are extremely important and should not be sacrificed. It is also true that we must provide sufficient background knowledge to permit our graduates to be flexible in adjusting to the changing conditions of their profession. How many of us have tried to answer the question, for our specialized area, "How much must all civil engineering graduates know?" Frankly, after 4 years of thinking about the question the answer is still very vague because of complications of both technical and administrative nature. Nevertheless, active thought and discussion have caused us to develop a new undergraduate program which is substantially different from our offerings of only 5 years ago.

Correlative Instruction

Departing from the situation at Illinois for a moment, Table 1 purports to show the arrangement of courses in hydraulic engineering, or courses containing substantial hydraulic engineering material, which was prevalent during the early 1940's. Undergraduate programs had not yet begun to reflect the swing to fluid mechanics. Many of us were still teaching more or less empirical hydraulics in conjunction with a laboratory course which demonstrated the fact that the rate of flow over a weir was indeed equal to 3.33 times the length of the weir times the head on the weir raised to the three halves power. We spent very little time on items such as Reynolds number, dynamics of flow, and drag of immersed bodies.

TABLE 1

CORRELATIVE PATTERN OF INSTRUCTION

Course	Type of Development	Registration
Hydraulics	Empirical	All civils
Hydraulic laboratory	Demonstration	All civils
Water Supply	Methodology	All civils
Sewerage and sewage treatment	Methodology	All civils
Highways	Methodology	All civils
Water Power	Procedures	Hydraulic majors
Irrigation	Procedures	Hydraulic majors
Drainage	Procedures	Hydraulic majors

After our students had completed the hydraulics and hydraulics laboratory course they were through with hydraulic engineering as an integrated subject matter. From this time on, most of the hydraulic engineering material was encountered as a part of an application course. For example consider the water supply work. Our water supply courses included rainfall and runoff, mass curves, dams and impounding reservoirs, and ground water. As a matter of fact oftentimes the chemical treatment of a water supply and the distribution work were neglected for the hydraulic engineering material which was included. The sanitary engineering instructors, and the text authors, followed this procedure because they believed sufficient background had not been established for them to proceed to higher levels of work.

During the same period the highway engineering courses devoted considerable time to drainage. This included use of the rational equation for design of street inlets, exposure to the rational method and empirical methods of determining culvert sizes, and in some few cases discussion of flow through culverts. In many cases some material relative to subsurface flow and the use of drain tile was presented in the highway engineering courses.

The preceding courses were required of all civil engineers and were usually taught by individuals who specialized in the particular application phase of civil engineering. Finally, after completing this broad background of non-integrated water supply, sewerage, and highway work, the undergraduate who decided to follow the hydraulic speciality was able to choose a course in water power, irrigation, or drainage. Oddly enough during the forties, when we offered less basic

information than we do now, the student had a greater opportunity to specialize.

The table also indicates the apparent type of development which was followed in each of the courses. You will note that the hydraulic work was largely empiricism and demonstration of the accuracy of that empiricism. In general, the application courses required of all civil engineering undergraduates were methodology courses, oftentimes augmented by additional empiricism. Finally, the specialty courses which were followed by the hydraulic majors appear to have been composed of assembled design procedures for a given product or prototype facility. In many cases this material was developed, after very careful study, by practicing engineers.

Because of the nature of the preceding course schedule and content, it is lumped together and termed a correlative pattern. It appears that our programs of that day were principally concerned with correlating the information and art which were available at that time in an effort to turn out the best possible practicing engineer.

Importance of Hydrology

Viewing the work of the forties and the early fifties with hindsight, and this is always the safest procedure, we see that the key to the reorganization of the instructional pattern is in the one word "hydrology." Early in this discussion it was pointed out that two major movements have been responsible for the development of a more logical pattern of undergraduate education. The first of these was the change from empirical hydraulics to rational fluid mechanics and the accompanying integration of the fluids material with basic science. Curriculum changes caused by the new emphasis in the hydraulics and fluid mechanics area were substantially confined to the content of one or two required courses. Thus it was relatively simple to take advantage of the new fluid mechanics attitude within the established course structure.

Introduction of hydrology on the more scientific and integrated basis was not so easily accomplished. As indicated previously, material which is now considered to be grouped under the title "Hydrology" was originally scattered through at least three non-hydraulic engineering courses. Separation of the hydraulic engineering items from these courses appeared to be very difficult if not, in fact, undesirable. Because of this we continued to offer explicit hydrologic material within the application courses for many years after basic hydrologic information was available. At that time it was logical that we do so. For example, the sanitary engineer correctly believed that the use of a mass curve could be illustrated as properly in determining the required capacity of a water supply reservoir as with any other topic. He felt that the flow in pipes, either full or partially full, was typically a problem in sanitary engineering because of his interest in design of sewer systems and water distribution systems.

The sanitary engineer was not particularly concerned with floods, but the highway man was vitally concerned. Consequently the prediction of flood flows, the determination of flood frequencies and the evaluation of how flood waters reached the highway embankment were left to the highway engineer. Similar reasoning applies to the allocation of subsurface drainage: partly in sanitary engineering, so far as ground water supplies are concerned, and partly in the field of highway engineering, so far as the stabilization of roadway bases is concerned. Inclusion of this hydrologic material in the application course offerings served to very definitely impress the highway and sanitary people with the importance of hydrology. Because they recognized that they were treating only a portion of the total subject, they, as much as anyone, were dissatisfied with the lack of integration.

With this background, and with the pressure for additional time within the application courses for development of specific technical material, it became obvious that the logical solution was to combine all of the hydrology work in a new course to be taught by members of the hydraulic engineering staff. Development of this course required evalua-

tion of the entire field of hydrology and the delineation of material that should be presented to all civil engineering students.

One of our best authors has defined hydrology as follows: "Hydrology is the science that deals with the processes governing the depletion and replenishment of the water resources of the land areas of the earth." There are two facets of this definition which are particularly appealing. The first is the definition of hydrology as a science. While this may be viewed with some skepticism by our brethren in the areas of physics, chemistry, and the life sciences, surely no one who is familiar with the controlled experiments and rational classifications of hydrologic material can question the statement. It is true that hydrology is an earth science and as such covers an area of endeavor in which strictly controlled experiments and analyses are extremely difficult. It is also true that scientific study of hydrology is much more recent than empirical study. The second portion of the definition which is appealing is the reference to "water resources" of the land areas of the earth. This is not only the most important phase of hydrology, but is also the key to the future of hydraulic engineering. It is one thing to view hydrology as a study of rainfall and runoff and quite another to consider it as an inquisition into the performance of water as one of the chief resources of the earth.

With our increased understanding of hydrology, hydraulic engineering has grown to the point where water is not merely a domestic supply, an agricultural supply, or a runoff problem. We are more and more looking upon water as the common medium. It falls from the skies and runs off from the ground and into our storm drains. In this phase it is a problem of disposal. It flows in our streams and is here an agent for modification of the topography and a major component of recreation and transportation. It is impounded in surface or subsurface reservoirs and is then used for domestic or industrial consumption or for the development and processing of manufactured goods. It is then used as a vehicle for the disposal of wastes, and under optimum conditions it is re-treated and returned to the stream or river for further use as a medium of transportation, as a medium for the development of electrical energy, as a source of supply for irrigation projects, and in many cases as the target of flood control works.

Acceptance of the widespread uses, both advantageous and disadvantageous, of natural water in its many different forms represents a coming of age of hydraulic engineering work. The key to this coming of age is the understanding of hydrology. This is true not only so far as nucleation in the heavens and runoff over the ground surfaces are concerned, but of much more importance, insofar as the total uses of man are affected.

Rational Instruction

The problem of introducing a new required course in hydrology was a complex one. At Illinois it was necessary to change the hours of credit for several courses already in the curriculum and also to chronologically relocate the fluid mechanics work. The latter action was dictated by the fact that fluid mechanics should be offered concurrently with hydrology, and for hydrology to properly serve its function as a service course it was necessary that it be completed by the end of the junior year. Only if this is done can the sanitary, highway, and hydraulic people properly utilize the principles of hydrology and fluid mechanics in their courses of specialization. Failure to satisfy this goal renders the required hydraulic engineering course impotent so far as upper division work in any of the specialized areas is concerned.

The course offerings which we have adopted at Illinois are indicated in Table 2 under the heading of "Rational Pattern of Instruction." This might more logically be titled "Present Pattern of Instruction" because we feel there is much to be done to make our schedule more rational, and secondly because it sometimes appeared the developmental work was based on obvious irrationality.

All of the courses listed in the table, except for the fluid mechanics work, are taught by the hydraulic engineering staff

TABLE 2

RATIONAL PATTERN OF INSTRUCTION

Course	Type of Development	Registration
Fluid Mechanics	Rational Analysis	All civils
Fluid Mechanics Laboratory	Development	All civils
Hydrology and Engineering Hydraulics	Empirical to Rational Analysis	All civils
River Hydraulics	Rational to empirical	Hydraulic majors
Water Resources	Development and methodology	Optional
Hydraulic Structures	Rational and methodology	Optional
Earth Dams	Rational and methodology	Optional
Hydraulic Engineering Laboratory	Rational and methodology	Optional

of the Department of Civil Engineering. The two courses in fluid mechanics are offered by the Department of Theoretical and Applied Mechanics, and we are fortunate to have the staff and facilities for an excellent job. Much of our hydraulic engineering development is due to the helpful and cooperative efforts of members of that Department. In addition to the required courses in fluids the Department of Theoretical and Applied Mechanics offers very good undergraduate courses in fluid mechanics and advanced hydraulics and in dimensional analysis and theory of models, which are open to, and are very popular with, our students as optional courses.

Our undergraduate student normally registers for the hydrology course and the two fluid mechanics courses during the first semester of the junior year. While this procedure does cause some difficulty in the organization of the hydrology work, because the fluid mechanics background is being developed concurrently, it is necessary for hydrology to be completed at this time.

In the hydrology course we make every effort to develop the known scientific facts about sub-areas of information and then to illustrate the value of the known information to the design engineer and his employer. Our vehicle for this process is the design problem. As an example consider the final design problem from the past semester. The student had already studied the unit hydrograph, flood frequency and flat-pool storage relationships. His assignment in the final design problem required finding fifty-year flood flow and then determining the size and cost of three culverts, one with uniform cross section, the second with taper-throat, and the third flowing full at outlet. For this particular problem he found that the three culverts, with uniform cross-section, with tapered-throat, and flowing full at outlet, would cost approximately $44,000, $39,000, and $36,000, respectively. Upon completion of the design work the student submitted a well written design report which brought together his hydrologic and hydraulic design, his cost estimate (which was a very minor portion of the work), and his conclusions. It was our intent that this student, regardless of his specialty, would remember that for super-critical slopes, with culverts part full, the control is at entrance; that the shape of entrance may substantially reduce construction costs; and that culverts flowing full, on super-critical slope, have a very significant design advantage.

The hydrology course of the past semester included five design problems of this character. Since the last quarter of the course deals with open channel work, which is built on the concurrent fluid mechanics courses, the latter design problems have a more practical flavor than the initial ones. Our aim remains constant: to provide thorough grounding in the earth science and to effect some transition to engineering application.

Upon the completion of the course in

hydrology and engineering hydraulics, the student who does not elect to specialize in hydraulic engineering goes on to the required courses in sanitary engineering and highway engineering. Both of these areas have been able to very considerably expand their course content because of the deletion of the hydraulic engineering material. For example, our required course in highway engineering was formerly composed of approximately equal parts of hydrology and drainage, soils, and highways. Under the new program with the relocation of the hydrology and drainage material (and there has been a corresponding relocation of soil mechanics), the highway people are now able to offer a three-hour course which is concerned with transportation facilities, design and uses of pavements, and traffic. Similar expansion of the required course in sanitary engineering has been possible. Instead of a course in sewerage, sewage treatment, and water supply, the sanitary course now covers unit processes, treatment operations, stream sanitation, use and quality of water, and an introduction to industrial sanitary engineering and environmental sanitation.

The student who elects to specialize in hydraulic engineering usually takes the river hydraulics course during the second semester of his junior year. This course is designed to form the transition from fluid mechanics and hydrology to applications of hydraulic engineering. Organization in the river hydraulics course is patterned after the river basin. The student is first introduced to the functions of rivers and streams from the hydraulic, physiographic, economic, and social aspects. His proficiency in handling flow in open channels, with uniform, non-uniform, and non-continuous conditions, is increased. He is provided with a good background in natural channels, and he performs and becomes familiar with stream gaging computations and with the several specialized techniques of computation which are used to convert stage hydrographs to discharge hydrographs. The second portion of the course deals with mechanics of streams. Included in this category are studies of the hydraulic geometry of streams, stream and surface erosion, stream deposition, and stream pollution. The final third of the course includes evaluation, and sometimes preliminary design, of specific channel flow structures such as levees, floodways, revetments, and degradation control structures. One of the principal efforts in this course is the completion of the term problem in which the students, working as design groups, prepare a semi-professional report on a particular application of river hydraulics to engineering design. During the last semester the term problem was a study of river channel flood routing through a short reach of one of the major Illinois streams.

Completion of the course in river hydraulics places the student in a position to elect his two additional speciality courses in hydraulic engineering. The courses from which he usually makes his choice include water resources, earth dams, hydraulic structures, and hydraulic engineering laboratory. He may select one of the fluid mechanics courses cited earlier, or a course in water supply and waste water systems, meteorology, geomorphology, or agricultural climatology. It is our intent that with the two optional courses the man may bend his training in the direction of his maximum interest. Each of the five senior year optional courses in hydraulic engineering is maintained at a professional level and is aimed at providing transition and development from the hydrology and river hydraulics work to a specialized area of the field.

We feel that we have accomplished two major objectives in the reorganization of our undergraduate hydraulic engineering program. First, and probably the most important, all civil engineering students are now receiving a background in the natural earth science hydrology. This is important to all phases of civil engineering because it is no longer possible for us to perform our work, with all its economic implications, without considering items such as the occurrence and frequency of floods, distribution and intensity of rainfall, and the factors controlling occurrence and movement of ground-water. Secondly, a much more specific and scientific back-

ground is provided for the students who elect to specialize in hydraulic engineering. We are all aware that there is a vastly increased need for specialists in this field.

Importance of Water Resources

The recently completed curriculum changes are viewed as only a partial completion of necessary growth and adjustment. This limitation is based upon the belief that within the near future the United States and indeed the world will experience a tremendous surge in the development and analysis of water resource projects. The numbers of our population, the intensity with which we till our fields, the requirements of industry, and the need for recreational areas in which to spend increased leisure time all indicate the requirement for well coordinated water resource plans for hundreds of river basins in this country alone. We are no longer in the position of being able to develop large numbers of single purpose reservoirs. It is now incumbent upon us to recognize the multiple use reservoir as the primary tool of river basin development. The river basin, which does not recognize political jurisdictions, requires interrelated work by adjacent governmental agencies. Cooperation in this type of endeavor must be evidenced from the initial conception and planning phase of a program to the time of water utilization. Throughout this long line of development there will be great need for competent hydraulic engineers, and for engineers in other specialties who have a firm background in the hydraulic engineering area. How we as civil engineering educators can integrate satisfaction of this requirement into an already crowded curriculum is the primary problem.

BOOKS BEAT TV FOR EDUCATION

Books are the most efficient teaching aids and television the least efficient, a specialist in instructional materials declared at The University of Michigan.

Perfection of a teaching aid as an educational tool hinges on the degree to which individuals can use it on their own terms, explained Louis Forsdale, of Horace Mann-Lincoln Institute of School Experimentation at Columbia University's Teachers College.

Forsdale described his method of evaluating teaching materials:

> Place all teaching aids on a line, with those most accessible to individuals at one end and those farthest removed at the other. Nearest the student would be books. At the opposite pole would be television. Films would be in the middle. Degree to which aids could be moved down the line toward individual control defines their effectiveness as teaching tools.

Forsdale said this principle assumes that individuals operate at various paces due to differences, that motivation changes with time and situation, and that repetition is desirable or necessary in the education process.

With television, individuals exercise no control over what they see and when, he said, adding that they can't repeat the experience as with books. "It would be an absurdity for an individual to ask television stations to televise this or that program for his benefit."

Forsdale said extensive educational use of video tape would be economically taxing, since taping machines cost upwards of $50,000 and require extensive training to operate.

Introduction of 8 mm. sound film and development and production of a cartridge loading film projector could lead to greater individual use of motion pictures as instructional materials, Forsdale said.

Use of cartridge loading projectors would make a variety of subjects available to school libraries and classrooms. Use would require skills any 6-year-old possesses, he explained.

Eight mm. sound film could lead to the same changes that the entrance of 16 mm. prompted in the 1930's. Film costs, projector portability and size would be affected, allowing wider usage, he said.